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TEXT-BOOK OF PHYSIOLOGY.

TEXT-BOOK

OF

PHYSIOLOGY,

GENERAL, SPECIAL, AND PRACTICAL.

BY

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WITH TWENTY-ONE PHOTO-LITHOGRAPHIC PLATES.

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PREFACE.

DURING the winter session 1841-42, I, for the first time, gave a course of lectures on Histology, in Edinburgh, and the following year, Mr Quekett gave a similar course in London. In 1848, when appointed to the chair of the Institutes of Medicine in this University, I began to teach Physiology systematically, and have done so every winter since then, while the lectures on Histology were delivered only in summer. In 1862, I was enabled to institute courses of instruction in Practical Physiology, as they are at present taught both during the winter and summer sessions, having obtained at that time a new laboratory, furnished with all the modern instruments of precision necessary for the purpose.

In 1858, under the title of "Outlines of Physiology," I published an extension of the article I contributed to the last edition of the *Encyclopædia Britannica*. The rapid exhaustion of a large edition of this little work, demonstrated the great demand that existed for a short treatise on the subject. But I have hitherto hesitated to write a text-book, apprehensive that the extensive field, theoretical and practical, now occupied by the science, would render the work too bulky. Thus a knowledge of analytical organic chemistry and of practical physics is at present admitted to be essential for comprehending and manipulating the instruments which in recent times have so largely assisted in advancing the subject—a knowledge not required in the medical curriculum. In yielding, therefore, at length to the earnest and repeated requests of my classes to furnish them with a book that would aid their studies, it has to be seen how far the attempt to condense in this volume so comprehensive a science will satisfy the expectations and meet the requirements of the physiological student.

The illustrative plates contain figures which have been chosen simply on the score of what has appeared to me their utility. Like the text, they are compressed into the smallest possible space, and have been produced by photolithography, in order to diminish cost. Some of them, in consequence, although sufficiently characteristic, may not be so perfect as good woodcuts, but the latter would have seriously increased the price of the book.

I have to thank my assistant, Dr McKendrick, for the valuable aid he has rendered me throughout the progress of the work, but more especially in the sections on the Physical Properties of the Tissues, on Practical Chemical Physiology, and on Practical Experimental Physiology, which were entirely written by him.

J. Hughes Bennett.

Edinburgh, *November 5. 1872.*

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INTRODUCTION.

Physiology is that science which treats of the phenomena observed in living beings. Of these, such as occur in plants are now taught by the Professor of Botany, and such as distinguish the lower animals are comprehended in the lectures of the Professor of Zoology. By Physiology, therefore, at present, is generally understood a knowledge of the functions of the human body—in other words, human physiology ; whatever facts, however, throw light upon this last branch of the subject, observed in any of the kingdoms of nature, are made available for the purpose. The student, after obtaining a certain knowledge of Anatomy—which teaches us the structure and relations of the parts of the body, as determined by dissection—should, in the first instance, study the chemical, histological, and physico-vital phenomena presented by the tissues of which the organism is composed. This has taught us that all function is dependent upon the alterations and actions upon one another of the ultimate molecules—chemical and histological—of which these tissues are made up, and that the sum of the forces they evolve, constitutes vitality. He should next pay attention to the special physiology of organs, which, according to the functions they subserve, are arranged into the three groups of Nutrition, Innervation, and Reproduction. Lastly, he should exercise himself in the methods and in the use of the instruments which have become so necessary for clearly comprehending and making additions to the truths of physiological science. This branch of the subject I have for many years taught in the Laboratory of this University under the name of Practical Physiology.

PART I.

GENERAL PHYSIOLOGY.

General Physiology comprehends, 1st, the Chemistry; 2d, the Histology; and, 3d, the Physical and Vital properties of the Tissues,—with the consideration of what is understood by life or vitality.

CHEMISTRY OF THE TISSUES.

At one time it was supposed that the peculiar character of the chemical compounds formed in living bodies was due to the action of a mysterious force, termed vital force, but later researches have shewn that many of those compounds may be produced in the laboratory, either by the direct combination of their elements, or by chemical changes produced in inorganic compounds. For example, cyanogen gas (C_2N) is a compound of carbon and nitrogen, and may be formed by the direct union of its elements. This, combined with ammonium, forms cyanate of ammonium, and by a molecular transformation of the elements of the latter, urea, a well known organic substance excreted by the kidneys, is formed. Thus :—

$$\underset{\text{Ammon. Cyanate.}}{CNNH_4O} = \underset{\text{Urea.}}{COH_4N_2}$$

In like manner, a large number of organic compounds, known as alcohols, aldehydes, acids, ethers, amines, &c., may be prepared from hydrocarbons, such as marsh gas and ethylene. But although many of the proximate principles of animals may be prepared artificially by ordinary chemical actions without the agency of a vital force, we cannot for a moment suppose that chemistry alone will ever succeed in producing even the simplest plant or animal.

Chemical Elements.

As there have lately been changes in the chemical doctrines concerning atoms, and their symbols, relative weights, and powers, it is necessary before we enter upon a detailed examination of the chemistry of the body, to explain certain terms often employed.

1. By an "element" is meant matter which by no known chemical means can be resolved into two or more heterogeneous substances. For example, it is at present impossible to split oxygen or hydrogen into any other substances—hence they are called elements.

2. An "atom" is the smallest amount of a chemical element which can exist in a compound. An atom is never found in a free state. An atom of hydrogen is represented by the symbol H.

3. A chemical "molecule" is a combination of two or more atoms, and the atoms may be atoms of the same or of different substances. A molecule can exist by itself. A simple molecule, made up of two atoms of the same element, is seen in the case of a molecule of hydrogen = HH. A molecule of hydrochloric acid is made up of a combination of an atom of hydrogen with an atom of chlorine = HCl.

The limits up to which the number of atoms in a molecule may increase are at present unknown. According to Dr Thudicum,[*] a molecule of hæmatocrystallin, the principal ingredient of the blood corpuscles, is represented by the formula $C_{600}H_{960}N_{154}Fe\,S_3O_{177}$, representing 1895 atoms. It is remarkable that by the law of condensation, if these 1895 atoms could be brought into the gaseous state, they would occupy two volumes, the same space as would be filled by a molecule of watery vapour containing three atoms.

The elementary chemical substances at present known in nature are sixty-five in number. Of these thirteen are non-metallic, and fifty-two are metallic. Only twenty out of this number enter into the composition of organized beings, namely, *Non-metallic Elements*—Oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, chlorine, fluorine, iodine, bromine, and silicon ; *Metallic Elements*—Potassium, sodium, calcium, magnesium, aluminium, iron, manganese, copper, and lead.

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[*] Tenth Report of Medical Officer of Privy Council, 1867. Appendix, No. 7, Dr Thudicum's Report.

Of these twenty elements, the most essential are oxygen, hydrogen, carbon, and nitrogen, which may be regarded as the basis of all organic matter.

Oxygen, the most abundant of all the elements, is an essential constituent of all living organisms, independently of its existence in the water of the tissues.

Hydrogen also exists in the water of the tissues, of which it forms one-ninth by weight, and it is found in almost all organic matters.

Carbon is the characteristic element of organic bodies ; so much so, that when any substance exposed to heat on a piece of platinum foil becomes blackened or charred, from the separation of carbon, it is known to be of organic origin. Carbon is associated with oxygen and hydrogen to form many of the simpler organic compounds.

Nitrogen. In more highly organised substances such as albumin, fibrin, and casein, nitrogen is superadded. Free nitrogen is said to be found in the air bladders of fish, and in other cavities of the animal body.

Phosphorus is found in the urine (where it was first discovered), in blood, and in the proximate principles, albumin and fibrin, which enter so largely into the composition of all the soft tissues. It also exists largely in nervous tissue, and in bone, where, in combination with lime, it forms tribasic phosphate of calcium, the chief mineral constituent of that important structure.

Sulphur is necessary to the constitution of albumin, fibrin, and casein, and it exists in the taurin of bile, and the cystin of urine. It also forms sulphates in combination with oxygen and various bases.

Chlorine exists chiefly in combination with sodium and potassium, forming chlorides of sodium and potassium—the former being a most important constituent of all animals.

Fluorine has been found in very small quantity in the ash of blood, milk, and bone.

Iodine and *Bromine* have been found in the secretions of persons taking cod liver oil, or in the habit of eating marine plants and animals, all of which contain these substances.

Silicon, in form of silicic acid, is seldom absent from the ash of organic matters, though it exists in very small quantity. According to Gorup Besanez, it forms a constituent of feathers and of hair.

Potassium-salts enter largely into the composition of the body, forming essential constituents of many organs and fluids, as for instance, flesh and milk. They are derived chiefly from the vegetable kingdom.

Sodium in combination with chlorine, sulphuric, phosphoric, carbonic, and various organic acids, exists in every tissue of the body.

Calcium exists in the bones of animals, as carbonate and phosphate, and it also combines with organic acids.

Magnesium in the form of carbonate and phosphate, is found in flesh, blood, milk, urine, &c.

Iron is one of the most important elements of the body, as it forms about seven per cent. of hæmatin, the red colouring matter of the blood corpuscles.

Aluminium, *Manganese*, *Copper*, and *Lead*, are only occasionally found in the tissues, and their presence may be accounted for by some peculiarities in the chemical nature of the food used. It has also been suggested that the copper and lead, rarely met with, may have been derived from the apparatus made use of in the chemical research.

COMPOUND RADICLES.—Numerous hypotheses have been advanced to explain how the twenty elementary substances above mentioned combine to form the tissues of a living being.

Before the days of Dumas and Liebig, the opinion generally held was, that the elements oxygen, hydrogen, nitrogen, and carbon, combined to form ternary and quaternary compounds, which made up the tissues and fluids of the body.

M. Raspail taught that oxygen and hydrogen first united to form water, which, entering into combination with carbon, formed a ternary compound. In the same manner, nitrogen entered into the composition of the tissues, through the agency of an ammoniacal salt, and the union of this salt with water formed nitrogenised organic matter.

The next theory was that of Liebig, which has been termed the theory of compound radicles. Among the numerous substances derived from the organs of an animal, groups are found, the members of which exhibit a close analogy with each other, both in chemical constitution and in the decompositions they undergo. For example, each member of the following series of alcohols, contains an atom of carbon, and two atoms of hydrogen, less than the one immediately above it.

Wood spirit,	CH_4O.
Ethylic alcohol,	C_2H_6O.
Propylic alcohol,	C_3H_8O.
Butylic alcohol,	$C_4H_{10}O$.

Each of these compounds is evidently analogous to wood spirit, but contains an additional number of multiples of the hydrocarbon CH_2, and the group forms what chemists term a homologous series. By various chemical processes, each alcohol yields an ether, an aldehyde, an acid, &c., and these derived compounds form a heterologous series. Liebig explains this similarity existing between members of such a homologous series, by the hypothesis that in each of them there is a certain group of elements, which he terms the radicle of the series—the radicle of the above series being methyl (CH_3). Thus wood spirit is the hydrated oxide of methyl (CH_3HO). The ether derived from wood spirit, is the oxide of the radicle $(CH_3)_2O$. A radicle may be simple or compound. The radicles of inorganic chemistry are usually simple; those of organic chemistry are complex; but in either case, the radicle plays the part of a base and discharges a function analogous to that of potassium and its salts.

In carrying these general views into detail, M. Dumas made the beautiful generalisation, that an animal should be regarded, in a chemical point of view, as an apparatus of combustion, which incessantly returns to the atmosphere carbonaceous matters in the shape of carbonic acid (CO_2), hydrogen as a constituent of water (H_2O), and free nitrogen in the form of ammonium oxide (NH_4O). In short, from the animal kingdom as a whole, there is constantly given off carbonic acid, watery vapour, and nitrogen. Vegetables, on the other hand, absorb and fix these substances, retaining the carbon and hydrogen, and setting free the oxygen. They also abstract nitrogen directly from the air, or indirectly from ammonium oxide, or nitric acid. Vegetables, for the most part, form organic matter under the influence of solar light. They pass ready formed, as food into the bodies of animals, which, during their life, or after their death, restore them to the atmosphere from which they were originally derived. Thus the animal kingdom is an apparatus of combustion, the vegetable kingdom an apparatus of reduction; the one produces the elements which the other consumes; so that, in the language of Dumas, they are the "offspring of the air." They come from the atmosphere, and return to it again.

The various mineral matters which enter into the constitution of living beings, exhibit the same dependence which animals have upon vegetables, and these, again, upon inorganic matter. They simply pass through living beings, as it were, to serve certain important purposes in the scheme of life. Let us take lime and sulphur as examples. Rain water, loaded with the carbonic acid of the air, falls upon calcareous hills, and carbonate of lime, in a state of solution, enters rivers, and is by them carried to the ocean, where it is seized upon by millions of animals, and converted into their external skeletons or shells. The water of rivers and springs also is absorbed by plants, and drank by animals; and so lime enters into their substance, and is converted into various salts of that base, such as oxalates, tartrates, phosphates, &c. Phosphate of lime is the principal element of the bones, besides entering more or less into the constitution of the other tissues of the superior animals, which are continually excreting, as well as assimilating it. Lastly, on their death, the lime is dispersed in various ways; even the bones crumble to pieces; and so the mineral returns to the soil, from whence it came. Sulphur passes from one region to another, in a similar manner, from the sea, which contains sulphur in large quantities, to the atmosphere, thence to the soil, and thence to plants and animals, from whence again it returns to the bosom of the ocean.

These incessant exchanges between the soil or atmosphere, plants, and animals, constitute the theory known as "the chemical balance of organic nature."

PROXIMATE PRINCIPLES.

The various elements above enumerated arrange themselves under the influence of chemico-vital laws, to form what are termed "Proximate principles." A proximate principle, strictly speaking, is any substance, whether simple or compound, which exists under its own form in the animal solid or fluid, and which can be extracted by means which do not alter or destroy its chemical properties. For example, tricalcic phosphate is a proximate principle of bone ; but phosphoric acid is not so, since it does not exist as such in bony tissue, but is produced only after the decomposition of the tricalcic phosphate ; still less phosphorus, which is obtained only by decomposing the phosphoric acid by the action of charcoal.

The chemical proximate principles, which are of such paramount importance, in constituting the substance of the body, may be divided into four groups—namely, 1st. the albuminous ; 2d. the fatty ; 3d. the mineral ; and, 4th. the pigmentary principles. All these are more or less associated together in every texture and fluid, but some abound in one, and others in another, giving to each peculiar characters.

1. The Albuminous Principles.

The albuminous principles are divided into, 1st. Albuminates ; 2d. Albuminoids ; and, 3d. Albuminous derivatives.

Albuminates.—Mulder supposes that all the albuminates contain the same radicle $C_{18}H_{27}N_4O_6$, which he terms *protein*, combined with small quantities of sulphur and phosphorus.

1. *Albumin.*—Composition in 100 parts—C53·3,H7·1,N15·7, O22·1,S1·8 (Lieberkuhn). Various chemists have found a very small proportion of phosphorus in albumin. According to Mulder, albumin is a compound of protein and a hypothetical substance termed sulphamide—

$$5C_{18}H_{27}N_4O_6 + N_2H_4S = C_{90}H_{139}N_{22}SO_{30}.$$

Protein. Sulphamide. Albumin.

Albumin forms the white of eggs, where it exists as albuminate of sodium, and it occurs in large quantity in all the animal fluids which contribute to nutrition. It is also found in most of the animal solids. It does not occur in the body in a free state, but is always associated with an alkaline base forming an alkaline albuminate. It exists in two forms—soluble and insoluble albumin—the former being easily converted into the latter by the agency of heat, as in the familiar example of boiling an egg ; but it is doubtful if albumin is ever present in the living body in its insoluble state.

Nearly all acids precipitate it from its solutions. Nitric acid does this so readily, that it is used as a test of the presence of soluble albumin. When boiled with hydrochloric acid, ammonium chloride, leucin, tyrosin, and other substances are formed. It is insoluble in alcohol and ether. It is precipitated by corrosive sublimate and potassium ferrocyanide. When distilled with manganese protoxide, and sulphuric acid, it is decomposed into acetic, propionic, butyric, and benzoic aldehydes, with the corresponding acids. Two modifications of albumin, derived from pathological fluids, have been described, —paralbumin and metalbumin,—the former being not completely precipitated by heat, and the latter not being thrown down by potassium ferrocyanide.

This substance is of the greatest physiological importance. The egg of a bird contains hardly any other nitrogenous compound except albumin, the yolk containing, in addition, a yellow fat, with traces of iron and other organic matters. Yet we see in the process of incubation, during which no foreign matter except atmospheric air can be introduced, or can take any part in the development of the animal, that feathers, claws, blood corpuscles, cellular tissue, and vessels are produced.

2. *Fibrin.*— Composition in 100 parts—C52·7,H6·9,N15·4, O23·5,S1·2 (Mulder). Albumin may be converted into fibrin by oxidation, as may be shewn by passing a stream of oxygen through defibrinated serum, when the albumin in the latter is converted into fibrin, and separates in thirty-six hours in small clots. It is completely insoluble in cold water, in alcohol, and in ether. Fibrin is present in the body in a fluid state. It is found in small quantity in the blood (about 2·55 per cent.), lymph, and chyle. A variety of it, contained in solid muscular flesh, has been termed syntonin. Lehmann supposes it is formed in the organism from albumin, by the latter taking up oxygen. Until lately, fibrin was supposed to have the property of coagulating spontaneously, but recent researches by Dr Schmidt of Dorpat shew that its coagulation is due to the action upon it of another substance termed fibrino-plastic substance or globulin, a protein substance nearly related to albumin. The presence of air hastens the action.

3. *Casein.*—Composition in 100 parts—C53·8,H7·0,N15·1, O22·6,S1 (Moleschott). These numbers agree closely with the analyses of albumin, except that less sulphur is present in casein. It is slightly soluble in water, and it differs from albumin in the

solution not being coagulable by heat. It is precipitated by all acids, except carbonic acid, and is redissolved in excess. It is also precipitated by all earthy and metallic salts, and by potassium ferrocyanide. Casein constitutes the chief ingredient in the milk of the mammalia. It has also been found in very small quantity in morbid bile, in the fluid of cellular tissue, in flesh-juice, and in the small intestine of the human fœtus. It constitutes the envelope which surrounds the globules of oil or butter which float in milk. Rennet, which is an infusion of the mucous membrane of the fourth stomach of young calves, readily coagulates casein, the cause of this peculiar action being unknown.

4. *Myosin.*—This substance constitutes the gelatinous mass obtained by squeezing pulverised flesh from which all blood has been removed. The fluid part of muscle, or muscle-plasma, consists of myosin, or muscle-clot, and muscle-serum. Myosin gives the usual albuminoid reactions. It differs from blood fibrin in coagulating in a gelatinous mass,—not forming molecular fibres, as will be described in referring to the fibrous elements of the tissues. When myosin is dissolved in dilute acid, it becomes converted into another nearly allied substance, *syntonin.* Syntonin is insoluble in solution of sodium chloride, but in a ten per cent. solution of this salt, myosin is readily soluble. Syntonin is, however, not a special product of muscle, as it may be prepared by acting upon any albuminoid with hydrochloric acid.

5. *Globulin* or *Crystallin.*—Composition in 100 parts—C54·5,H6·9,N16·5,O20·9,S1·2 (Funke). This albuminous substance is found in the crystalline lens of the eye, and, according to some chemists, in the blood corpuscles. It forms a yellowish transparent mass when extracted from the lens by ether and alcohol. It is precipitated by all acids, including carbonic acid, and is redissolved by passing a stream of oxygen through it. According to Valenciennes and Frémy, the crystalline lens of fishes contains a substance called phaconin.

The ALBUMINOIDS constitute another group of substances nearly related to the albuminates, and no doubt derived from them. They are such bodies as Gelatin, Chondrin, Elastic stuff, or Elastin, Mucin, Pyin, Pepsin, and Ptalyin.

1. *Gelatin.*—Composition in 100 parts—C50·9,H7·2,N18·3, O and S23·6 (Gorup Besanez). It is obtained by boiling animal membranes, skin, tendons, &c., or by macerating bone in dilute

hydrochloric acid. When allowed to cool, it becomes a semi-solid, tremulous jelly, and if allowed to dry, it becomes elastic, vitreous, brittle, and hard. It is not precipitated by any acid except tannic acid. Though nearly allied to the protein compounds, it differs from them, and hence it has been found that animals fed exclusively on this substance die of starvation, as nutritive blood cannot be formed from it.

2. *Chondrin.*—Composition in 100 parts—C49·5,H7·1,N14·4, O and S28·9 (Gorup Besanez). This substance nearly resembles gelatin. It may be obtained by boiling permanent cartilage, such as those of the ribs or larynx. It is, when dry, a horny, hard, diaphanous substance. Solutions of it give a precipitate with all acids, alum, aluminium sulphate, plumbic acetate, and ferric sulphate,—thus differing in a remarkable manner from gelatin.

3. *Elastin.*—Composition in 100 parts—C55·65,H7·41,N17·74, O19·20 (Tilanus). This is found in ordinary yellow elastic tissue, of which it forms the chemical basis. It contains no sulphur. It is quite insoluble in boiling water, thus differing from white fibrous tissue, which yields gelatin on boiling.

4. *Mucin.*—Composition in 100 parts—C52·4,H7·0,N12·8, O27·8 (Scherer). This is the most important chemical constituent of mucus, the secretion of mucous membranes. Dilute acetic acid and mineral acid precipitate it. Heat produces no coagulation.

5. *Pyin.*—Composition in 100 parts—C51·69,H6·64,N15·09, O26·58 (Gorup Besanez). It is a constituent of pus, a pathological product the result of diseased actions of the animal body. It resembles mucin in its general characters, but differs in being precipitated by mercuric chloride.

6. *Pepsin.*—Composition in 100 parts—C56·7,H5·6,N21·1, O16·5 (Vogel). The active principle of the gastric juice is a ferment which acts powerfully on all protein bodies, forming derivatives which have received the name of peptones. It is prepared in great purity by treating an infusion of the glandular layer of the stomach with dilute tribasic phosphoric acid. Lime water is added, and the precipitate of calcic phosphate, along with the pepsin, is collected and treated with dilute hydrochloric acid. Having been again precipitated by lime water, the deposit is dissolved in dilute acid. To this second solution, a solution of cholestrin is slowly added, and the cholestrin, with the

pepsin entangled in it, is treated with ether. The ether dissolves out the cholestrin, and the remaining liquid is filtered. The filtrate contains the pepsin, with gives no precipitate with mineral acids, tannin, or mercuric chloride. Pepsin is most active in a dilute acid solution at the temperature of the human body. It is found in the urine, and Brücke found it in flesh.

7. *Ptyalin.*—This albuminous substance is the supposed ferment of the saliva. It contains sulphur. According to some physiological chemists, it converts starch, glycogen, &c., into sugar, by causing them to combine with water.

8. *Protagon* or *Myelin.*—This substance is distantly related to the albuminous substances above described. It is the chief constituent of nervous tissue, and is the parent of cerebrin, cerebric acid, &c. It may be extracted from brain-substance by ether and alcohol ; but it is easier obtained from yolk of egg by the same reagents. When purified and well washed, it is a white substance, crystallising in acicular bundles. Its composition according to Liebreich, its discoverer, is $C_{116}H_{291}N_4PO_{22}$. Regarding the histological importance of this substance, see Molecular elements of the Tissues.

9. *Quinoidine.*—Another substance, named animal quinoidine, was discovered by Bence Jones and Dupré, in all animal tissues, especially in the crystalline lens. It resembles quinine in its chemical characters and optical properties.

ALBUMINOUS DERIVATIVES.—The albuminous principles above described, undergo a disintegrating process in the tissues, and the result of this process is the formation of a number of compounds, which are excreted from the body. They are—

1. *Glycocholic Acid.* — $C_{26}H_{45}NO_6$. In combination with sodium, this acid exists in large quantity in the bile. When obtained pure from ox bile, it crystallizes in bulky masses of white slender needles. It is not very soluble in hot or cold water, but is easily soluble in alcohol and ether. It turns the plane of polarization to the right.

2. *Taurocholic Acid.*—$C_{26}H_{45}NSO_7$. This acid exists as a sodium salt in the bile of most animals, along with glycocholic acid ; but in the bile of the dog it occurs free from the latter. It occurs as very fine silky needles, which, when exposed to the air, rapidly change into an amorphous transparent mass. It

differs from glycocholic by containing sulphur, and by being *easily* soluble in water.

3. *Uric Acid.*—$C_5N_4H_4O_3$. This very important acid occurs in small proportion in the urine of man. It is always to be found in the juices of the spleen, liver, lungs, and brain. It exists in excess in gout, and in various forms of bodily derangement, attended by the formation of urinary calculi. It may be easily extracted from the urine of serpents, or from guano. When anhydrous, it forms small white crystalline scales, but with a little water of crystallization, it forms large crystals. It is very nearly insoluble in water. When heated dry it decomposes into hydrocyanic acid, cyanuric acid, ammonium cyanate, urea, and ammonium carbonate. Under the microscope, it presents various crystalline forms, as found in urine, but they are generally rhombs with the obtuse angles rounded off, and occasionally dumb-bell crystals. Uric acid is a product of the incomplete oxidation of the tissues. Its most remarkable characteristic, is the readiness with which it is acted on by all oxidising agents. In this way, numerous definite compounds are produced, the chief being alloxan, alloxantin, allantoin, and murexide. The relation existing between these substances, will be apparent on studying their chemical formulæ.

Uric acid, ...	$C_5N_4H_2O_3H_2$.
Alloxan, ...	$C_4N_2H_2O_4$.
Alloxantin, ...	$C_8N_4H_4O_7+3\ H_2O$.
Allantoin, ...	$C_4N_4H_6O_3$.
Murexide, ...	$C_8N_6H_8O_6$.

When uric acid is subjected to the action of an oxidising agent, in the presence of water, it gives up two of its atoms of hydrogen to the oxidising agent, while the remainder, termed dehyduric acid, reacts with water, to form mesoxalic acid and urea. Thus—

$$\underset{\text{Uric acid.}}{C_5N_4H_4O_3}+\underset{\text{Chlorine.}}{Cl_2}+\underset{\text{Water.}}{4\ H_2O}=\underset{\text{Mesoxalic acid.}}{C_3H_2O_5}+\underset{\text{Urea.}}{2\ CN_2H_4O}+\underset{\text{Hydrochloric acid.}}{2\ HCl}.$$

Those two atoms of urea are, however, formed at two successive stages of the process, the first of which result in the formation of alloxan, and the second in its decomposition. Thus—

$$\underset{\text{Dehyduric acid.}}{C_5N_4H_2O_3}+\underset{\text{Water.}}{2\ H_2O}=\underset{\text{Alloxan.}}{C_4N_2H_2O_4}+\underset{\text{Urea.}}{CN_2H_4O}.$$

$$\underset{\text{Alloxan.}}{C_4N_2H_2O_4}+\underset{\text{Water.}}{2\ H_2O}=\underset{\text{Mesoxalic acid.}}{C_3H_2O_5}+\underset{\text{Urea.}}{CN_2H_4O}.$$

By removing two atoms of hydrogen from mesoxalic acid or alloxan, other acids are formed. The numerous bodies which have been in this manner obtained from uric acid, upwards of forty in number, may, according to Odling,* who has paid much attention to this intricate subject, be classified into, 1. Simple non-nitrogenous acids, such as mesoxalic acid ; 2. Bodies containing a residue of the acid, along with one residue of urea, or mon-ureides, such as alloxan ; and, 3. Bodies containing a residue of the acid plus two residues of urea, or the di-ureides, such as uric acid. "Hydrated uric acid differs in composition from two atoms of urea by the addition of three atoms of carbonic oxide CO, capable of oxidation into carbonic anhydride CO_2, and by that oxidation of generating a certain amount of heat, or its equivalent of motion.

$$\underset{\text{Water.}}{2\,H_2O} + \underset{\text{Uric acid.}}{C_5N_4H_4O_3} + \underset{\text{Oxygen.}}{O_3} = \underset{\substack{\text{Carbonic}\\\text{anhydride.}}}{3\,CO_2}\quad \underset{\text{Urea.}}{2\,CN_2H_4O_2}.$$

"Hence uric acid must be considered to result from an incomplete oxidation of nitrogenous tissue, whereby, in addition to urea, carbonic oxide is produced, instead of carbonic anhydride." Reptiles, whose motions are sluggish and temperature slow, excrete carbonic oxide in the form of uric acid, or urate of ammonia ; while mammals excrete perfectly burned carbonic anhydride. In the urine, uric acid is found in combination with ammonium and sodium. For crystals of uric acid and various urates, see Plate I., figs. 1, 2, 3, and 4, and description of plate.

4. *Urea.* COH_4N_2.—This substance is found in the urine of all mammals, especially in that of flesh eaters. It is also found in smaller quantity in the urine of birds and reptiles, and in the renal secretion of some animals of the lower orders. In a state of health, it exists in very minute quantity in the blood of man and of other animals, and it occurs occasionally in the perspiration, in the amniotic fluid, and even in the tissues. About 30 per cent. of the solid matter of the vitreous humour of the eye consists of urea. Considered chemically, it is isomeric with ammonium cyanate ($CNNH_4O$) and with carbamide ($N_2(CO)''H_4$), and it may be formed spontaneously by the transposition of the molecules of the former substance. The ammoniacal odour of

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* Lectures on Animal Chemistry, delivered at the Royal College of Physicians. By William Odling, M.B., F.R.S., &c. London, 1866.

decomposing urine is due to carbonate of ammonia, produced by the combination of water with urea, thus :—

$$\underset{\text{Urea.}}{COH_4N_2} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Ammonium carb.}}{(NH_4)_2 CO_3}$$

Urea is formed as a product of the decomposition of many complex organic substances such as creatin, uric acid, allantoin, &c. Its presence in the body is due to the transformation of the tissues under the influence of the oxygen of the air absorbed in the lungs, and it is the last term in the series of the retrograde metamorphoses. When obtained pure, urea usually crystallizes in long flat prisms without terminal faces, but in certain circumstances it forms quadratic prisms terminated by octahedral faces. It tastes like saltpetre, dissolves in its own weight of cold water, very readily in hot water, easily in alcohol, but is nearly insoluble in ether. Urea forms three sets of compounds : 1, with acids ; 2, with oxides and salts ; and 3, various substitution derivatives called compound ureas. The most characteristic salt is the nitrate ($COH_4N_2.HNO_3$) which appears even in dilute solutions of urea, on the addition of a drop of nitric acid, in the form of rhombic or hexagonal plates, the acute angle of which, as measured by the goniometer = 82°. The appearance of this salt affords an excellent test for detecting the presence of urea in any fluid. The most important compound of urea with a salt is with mercuric nitrate, and Liebig's process for the volumetric estimation of urea is based on the precipitability of urea by mercuric nitrate, forming a compound, the composition of which is represented by the formula COH_4N_2 2 HgO.

5. *Hippuric Acid.* $C_9H_9NO_3$ (Pl. I. fig. 5).—This acid exists in very small quantity in the urine of man, but it is found abundant in that of herbivorous animals. According to Dr Bence Jones, the urine of a healthy man contains from 0.03 to 0.04 per cent. of this substance. When benzoic acid is taken internally, hippuric acid speedily appears in the urine. This acid forms colourless transparent prisms, often of considerable size.

6. *Inosinic Acid.* $C_5H_8N_2O_6$ (?)—It is doubtful whether this acid, first isolated by Liebig, really exists as such in the body, but it is undoubtedly one of the derivatives of the albuminous group. It was found in the mother liquor of the preparation of creatin from flesh-juice, and appeared as an un- crystallisable substance, very soluble in water, and having a flavour of broth.

7. *Xanthin* or *Xanthic Oxide.* $C_5H_4N_4O$-.—This body occurs in a species of urinary calculus, and, according to Scherer, it is a normal constituent of the human body. It differs from uric acid only by one atom of oxygen, uric acid having O_3 while xanthic oxide contains only O_2. It may be prepared artificially from uric acid, from guanin, from muscular flesh, and from urine. It is a white scaly substance, nearly insoluble in water, and insoluble in alcohol and ether.

8. *Hypoxanthin* or *Sarcin.* $C_5H_4N_4O$.—This substance is a weak organic base, existing in muscle-juice, and only in small quantity. A substance very similar to it has been found in human urine, but chemists are not agreed whether this substance is really sarcin or guanin. It is obtained from the mother liquor in the preparation of creatin, and is a white crystalline powder.

9. *Cystin* or *Cystic Oxide.* $C_3NH_7SO_2$.—(Pl. I. fig. 6.)—This organic base is found in a very rare form of urinary calculus occurring in men and dogs, and when separated, is seen to be a yellowish, shining, confusedly crystalline substance, tasteless, neutral, insoluble in alcohol and water. It is remarkable for containing sulphur.

10. *Taurin.* $C_2H_7NSO_3$ (Pl. I. fig. 7 *a*).—This remarkable substance was first obtained from oxbile and hence its name: from *taurus*, a bull. It results from the transformation of taurocholic acid under the influence of acids and alkalies.

$$\underset{\text{Taurocholic acid.}}{C_{26}H_{45}NSO_7} + \underset{\text{Water.}}{H_2O} = \underset{\text{Taurin.}}{C_2H_7NSO_3} + \underset{\text{Cholic acid.}}{C_{24}H_{49}O_5}$$

Fresh bile is clarified from mucus by the addition of an acid, and filtered ; boiled with hydrochloric acid ; the decanted liquor evaporated nearly to dryness on the water bath, and the mother liquor extracted with alcohol. The liquid on cooling, yields taurin in the form of six-sided prisms, terminated by four and six-sided pyramids like those of common quartz. It has a cool taste, is soluble in water, but insoluble in alcohol and ether. It is remarkable for containing more than 25 per cent. of sulphur. When burned, fumes of sulphurous anhydride are evolved. Taurin is nearly related to isthionate of ammonium, one molecule of this substance, minus a molecule of water, yielding a molecule of taurin. It is never found in the free state in healthy bile, or in any other secretion.

11. *Allantoin.* $C_4H_6N_4O_3$.—(Pl. I. Fig. 8.)—This substance is one of the derivatives of uric acid, and may be artificially pre-

pared from it. It exists in the amniotic and allantoic fluids, and when isolated, is found to present the form of shining colourless prisms, very soluble in water, and also in alcohol.

12. *Tyrosin.* $C_9H_{11}NO_3$ (Pl. I. fig. 9).—This substance occurs ready formed, and always accompanied by leucin, in the liver and blood of the hepatic vein in certain states of liver-disorder; and it has also been discovered in the spleen and pancreas. Occasionally it is found in the urine, and it may result from the decomposition of any albuminoid substance under the action of acids, alkalies, or putrefactive changes. Artificially, it has been prepared from casein, from horn, and from cochineal. It crystallises from aqueous solutions in stellate groups of long slender needles, having a beautiful silky lustre, soluble in water, in alcohol, but not in ether. It forms definite compounds with acids and alkalies, and there are several derivatives of more interest to the chemist than to the physiologist.

13. *Leucin.* $C_6H_{13}NO_2$ (Pl. I. fig. 10).—First discovered in old cheese, leucin has since been found, associated with tyrosin, in the liver in certain forms of disease of that organ. It also occurs in the lung-tissue, in the thyroid and thymus glands, and especially in the pancreas. It may be obtained by the action of sulphuric acid upon gelatin, muscular flesh, legumin, wool, white of egg, horn, &c.; and when purified, it presents the appearance of soft nacreous scales, somewhat resembling cholestrin. When found in urine, it forms yellow-coloured balls. (See Pl. I. fig. 10.) It is sparingly soluble in cold, but readily in hot water; sparingly in alcohol, and insoluble in ether. It forms definite compounds with acids and bases.

14. *Glycocin* or *Glycocol.* $C_2H_5NO_2$.—This substance is sometimes called sugar of gelatin, on account of its sweetish taste, and its being produced by the action of caustic alkalies on gelatin or meat. It exists in glycocholic acid, one of the bile acids, which, when acted on by an alkali, is resolved into glycocin and cholic acid.

$$\underset{\text{Glycocholic acid.}}{C_{26}H_{43}NO_6} + \underset{\text{Water.}}{H_2O} = \underset{\text{Glycocin.}}{C_2H_5NO_2} + \underset{\text{Cholic acid.}}{C_{24}H_{40}O_5}$$

It may also be obtained from hippuric acid. It crystallises readily in flattened prisms or aggregated plates. It is sparingly soluble in water, slightly soluble in hydrated alcohol, insoluble in ether. It differs from taurin in being sweet instead of bitter, and in not containing any sulphur.

15. *Creatin.* $C_4H_9N_3O_2$ (Pl. I. fig. 11).—This important substance is nearly allied to creatinin, differing from it only by the elements of water. It has not yet been settled whether or not creatin, as such, exists in the body, or whether it results from the decomposition of creatinin in the process of preparation. These two substances may be easily converted one into the other, the action of acids changing creatin into creatinin, while the action of alkalies, creatinin into creatin. Liebig and Dessaignes are both of opinion that the creatin of muscular flesh is produced by the decomposition of creatinin. It has been found in the urine, in the blood, and, by Städeler, in the brains of pigeons and dogs. It may be prepared by making an aqueous extract of beef, evaporating in vacuo, exhausting the residue with alcohol, and the alcohol evaporated till the creatin crystallises out. Anhydrous creatin is an opaque white mass, inodorous, somewhat bitter, neutral. The hydrate of creatin is in the form of clear prisms. It is soluble in water and alcohol, but not in ether. According to Strecker, creatin may be regarded chemically as a compound of cyanamide (*i. e.*, urea *minus* water) and sarcosin. It is a very weak base.

16. *Creatinin.* $C_4H_7N_3O$ (Pl. I. fig. 12).—This substance exists in the urine to the amount of 0·5 per cent., in muscular flesh, and in blood. It may be extracted from any of these substances, and also by the action of strong mineral acids on creatin. It occurs in the form of colourless prisms. It tinges reddened litmus paper blue, and is soluble in water and in alcohol.

2. The Fatty Principles and their Allies.

The fatty principles are divided into, 1. True fats ; 2. Amyloid substances and sugars ; and, 3. Acids related to sugar.

1. True Fats.—The term fat was originally applied to all substances containing carbon, hydrogen, and a small amount of oxygen, which form oily liquids or greasy solids, leave a permanent stain on paper, burn with a bright flame with little or no soot, are insoluble in water, but soluble in alcohol and ether. The researches of Chevreul,* however, shewed that fatty substances may be subdivided into (1) non-saponifiable fats ; (2) saponifiable fats ; and (3) fatty acids or soap acids. He shewed that certain

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* Chevreul, "Recherches sur les corps gras d'origine animale." Paris, 1823.

fats (the non-saponifiable) undergo no change when boiled with alkalies, while others (the saponifiable) formed soaps when treated with aqueous alkalies or with certain heavy metallic oxides. The formation of a soap when a saponifiable fat is treated with an alkali or metallic oxide is called saponification and consists of the resolution of the fat into two products, viz., First, a fatty acid which combines with the alkali and forms the soap ; and, secondly, almost invariably, the substance called glycerin, a sweetish, clear, transparent fluid. These researches have since been confirmed and extended by those of Berthelot.*

A fat is a body of the type of three atoms of water condensed to one, thus—

$$\left.\begin{matrix}H_3\\H_3\end{matrix}\right\}O_3$$

in which three of the atoms of hydrogen are replaced by the triatomic radicle glyceryl, and three others by three atoms of any fatty acid radicle. Tristearin, for example, a fat abounding in beef and mutton suet, has this formula—

$$\left.\begin{array}{ll}\text{3 monatomic atoms of stearyl} \quad . & \left\{\begin{matrix}(C_{18}H_{35}O)\\(C_{18}H_{35}O)\\(C_{18}H_{35}O)\end{matrix}\right.\\ \text{1 triatomic atom of glyceryl} \quad . & (C_3H_5)\end{array}\right\}O_3.$$

1. *The non-Saponifiable Fats* are cholestrin and serolin. These substances remain perfectly unaltered after prolonged boiling with solution of caustic potash (KHO).

(*a*) *Cholestrin.* $C_{26}H_{44}O$ (Pl. I. fig. 13).—This fatty substance sometimes constitutes nearly the entire bulk of human gall stones. It has been found in the bile, in the blood, in the brain, in the yoke of egg, and in certain morbid products of the human body. It is readily prepared by crystallising pulverised biliary calculi from boiling alcohol. It is white, inodorous, tasteless, insoluble in water, readily soluble in hot alcohol, from which it is deposited in beautiful soft nacreous laminæ. It forms compound ethers when heated with acetic, butyric or stearic acids, shewing that it partakes of the nature of an alcohol.

(*b*) *Serolin.*—Boudet gave this name to a fat which he obtained by the action of ether upon dried blood serum. It is, according to this chemist, amorphous, but Verdeil and Marcet state that it crystallises in nacreous laminæ. Some chemists consider this substance to be merely a mixture of several fats of different melting points.

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* Berthelot, "Chemie organique fondèe sur la synthèse."

2. *The Saponifiable Fats* are very numerous, but the most important are stearin, margarin, and olein. When boiled with an alkali they are decomposed into an acid which, uniting with the alkali, forms a soap, glycerin being set free and rising to the surface. Considered chemically, they are the compound ethers of the triatomic alcohol glycerin, hence they have received the name of glycerides.

a. Stearin is a white crystallisable fat (Plate I. fig. 14), constituting the chief part of fat, soluble in about seven times its weight of boiling alcohol, and much more freely in hot ether. It exists in three modifications, differing from each other in the fusing point. These are termed monostearin, distearin, and tristearin. They are ethers formed from glycerin, by the replacement of one, two, or the whole of the atoms of the typical hydrogen of glycerin, by the monatomic radicle stearyl ($C_{18}H_{35}O$.)

$$\begin{array}{ccc}\text{Monostearin.} & \text{Distearin.} & \text{Tristearin.}\\ \left.\begin{matrix}(C_3H_5)\\ C_{18}H_{35}O\\ H_2\end{matrix}\right\}O_3 & \left.\begin{matrix}(C_3H_5)\\ 2(C_{18}H_{35}O)\\ H\end{matrix}\right\}O_3 & \left.\begin{matrix}(C_3H_5)\\ 3(C_{18}H_{35}O)\\ \ \end{matrix}\right\}O_3\end{array}$$

Among the numerous decompositions of stearin, the most interesting, from a physiological point of view, is that discovered by Bernard, namely, that stearin, mixed with pancreatic juice, yields an emulsion in which all the stearin is resolved into stearic acid and glycerin.

b. Margarin. $C_{54}H_{104}O_6$ (Plate I. fig. 15).—This substance constitutes one of the solid ingredients of human fat. When extracted by boiling alcohol, it crystallises in pearly scales or clusters formed of needles, which are fusible at about 47° C. Various chemists have isolated from fat a substance resembling this, and it is now generally believed that margarin is not a simple fat, but a mixture of palmitic and stearic acids. No ethers corresponding to the stearic ethers, already mentioned, have yet been obtained.

c. Olein.—Pure olein is colourless, and is a fluid even at freezing point. When exposed to the air, it is resenoid in appearance. Chevreul prepared it by boiling human fat in a flask, filtering after leaving the solution for twenty-four hours, concentrating, adding water, which separates the olein, exposing the product to cold, and separating the liquid from the solid portion by pressure. Resembling stearin, it occurs in three modifications, which are ethers of glycerin, in which one or more of the typical atoms of hydrogen are replaced by the radicle oleyl ($C_{18}H_{33}O$) as follows:—

Monolein.	Diolein.	Triolein.
$\left.\begin{matrix}(C_3H_5\\(C_{18}H_{33}O)\\H_2\end{matrix}\right\}O_3$	$\left.\begin{matrix}(C_3H_5)\\2(C_{18}H_{33}O)\\H\end{matrix}\right\}O_3$	$\left.\begin{matrix}(C_3H_5)\\3(C_{18}H_{33}O)\end{matrix}\right\}O_3$

3. *The Fatty Acids.*—These bodies are obtained chiefly by the saponification of saponifiable fats. They combine with bases to form salts, and may be separated therefrom in their original state by stronger acids. Stearic and palmitic acids may be taken as the type of one series of the fatty acids in which the general formula is $C_nH_{2n}O_2$; oleic acid is the type of a second series, the general formula of which is $C_nH_{2n-2}O_2$. A third series, having the general formula, $C_nH_{2n-2}O_4$, may be obtained by the oxidation of the two preceding groups—oxalic acid being an example. The following is a list of these fatty acids, arranged in the three groups just indicated:—

Stearic Acid Group. $C_nH_{2n}O_2$		*Oleic Acid Group.* $C_nH_{2n-2}O_2$		*Oxalic Acid Group.* $C_nH_{2n-2}O_4$	
Formic .	$C\ H_2\ O_2$			Oxalic .	$C_2\ H_2\ O_4$
Acetic . .	$C_2\ H_4\ O_2$			Malonic	$C_3\ H_4\ O_4$
Propionic	$C_3\ H_6\ O_2$	Acrylic .	$C_3\ H_4\ O_2$	Succinic	$C_4\ H_6\ O_4$
Butyric .	$C_4\ H_8\ O_2$			Lipic .	$C_5\ H_8\ O_4$
Valeric .	$C_5\ H_{10}O_2$	Angelic .	$C_5\ H_8\ O_2$	Adipic	$C_6\ H_{10}O_4$
Caproic .	$C_6\ H_{12}O_2$			Pimelic	$C_7\ H_{12}O_4$
Œnanthylic	$C_7\ H_{14}O_2$			Suberic	$C_8\ H_{14}O_4$
Caprylic .	$C_8\ H_{16}O_2$			Anchoic	$C_9\ H_{16}O_4$
Pelargonic	$C_9\ H_{18}O_2$			Sebaic .	$C_{10}H_{18}O_4$
Rutic . .	$C_{10}H_{20}O_2$				
Lauric . .	$C_{12}H_{24}O_2$				
Myristic .	$C_{14}H_{28}O_2$				
Palmitic .	$C_{16}H_{32}O_2$	Physetoleic	$C_{16}H_{30}O_2$		
Stearic .	$C_{18}H_{36}O_2$	Oleic .	$C_{18}H_{34}O_2$		
Arachidic .	$C_{20}H_{40}O_2$				
Cerotic .	$C_{27}H_{54}O_2$				
Melissic .	$C_{30}H_{60}O_2$				

a. The Stearic Series of Fatty Acids.

1. *Formic acid*—CH_2O_2—has been found in the blood, in the

urine, in the fluid of the spleen, in muscle-juice, and in the perspiration.

2. *Acetic acid*—$C_2H_4O_2$—probably exists in several of the animal secretions, but it usually results from the decomposition and oxidation of organic bodies.

3. *Butyric acid*—$C_4H_8O_2$—is found in perspiration, in muscle-juice, and, in combination with glycerin, in butter. When butter becomes rancid, it has a peculiar odour, produced by free butyric acid. It is a pure, colourless, transparent liquid.

4. *Valeric acid*—$C_5H_{10}O_2$—is a frequent product of the oxidation of fats, and of the putrefaction of albuminous substances.

5. *Caproic* ($C_6H_{12}O_2$), *Caprylic* ($C_8H_{16}O_2$), and *Rutic* ($C_{10}H_{20}O_2$) *acids* exist in butter in combination with glycerin.

6. *Palmitic acid*—$C_{16}H_{32}O_2$—is universally distributed in the fats of the animal kingdom, and has been obtained by Chevreul by the saponification of human fat.

7. *Stearic acid*—$C_{18}H_{36}O_2$—is the most important of the fatty acids of the group to which it gives its name. It was discovered by Chevreul as a constituent of the solid fats, especially in beef and mutton suet, but it is also to be found in butter, in human fat, in the fat of the goose, serpents, &c. It may be prepared by the saponification with soda-ley of beef or mutton suet, decomposing the soap with water and dilute sulphuric acid, and dissolving the acid in hot alcohol. When allowed to crystallise from such a solution, it falls as nacreous laminæ or needles, is tasteless, inodorous, and is distinctly acid. It forms stearates with bases, substitution compounds with chlorine and bromine, and a series of ethers.

8. *Propionic*, *Œnanthylic*, *Pelargonic*, *Lauric*, *Myristic*, *Arachidic*, *Cerotic*, *and Melissic acids* have never been found in the human body.

b. The Oleic Series of Fatty Acids.

Oleic acid—$C_{18}H_{34}O_2$—is the most important member of this series. It is difficult to isolate it owing to its tendency to combine with oxygen. It is obtained by saponifying the non-drying oils, such as almond oil, and solid fats. It crystallises from an alcoholic solution in dazzling white needles.

c. The Oxalic Acid Series.

Oxalic acid forms the lowest, and sebaic acid the highest, term of this group.

1. *Oxalic acid*—$C_2H_2O_4$—in combination with calcium as calcium oxalate (CaC_2O_4), is often found in the urine, in urinary deposits, and calculi, in the allantoic fluid, and in the mucus of the gall bladder. It occurs in the form of square-based, octahedral crystals, and occasionally in the form of dumb-bells. (Plate I. fig. 17.) Recent researches have shewn that oxalic acid is nearly related, in chemical constitution, to many of the derivatives of uric acid already noticed. Many of these bodies may be regarded as amides (or ammonia substitution compounds) of oxalic acid—being derived from two or more molecules of oxalic acid by addition of ammonia and abstraction of water. As these processes may indicate what takes place in the living body, a few examples are here given.

$$\underset{\text{Oxalic acid.}}{2C_2H_2O_4} + \underset{\text{Ammonia.}}{2NH_3} - \underset{\text{Water.}}{4H_2O} = \underset{\text{Alloxan.}}{C_4H_2N_2O_4}$$

On introducing a molecule of another acid, we have decompositions like the following:—

$$\underset{\text{Oxalic acid.}}{C_2H_2O_4} + \underset{\substack{\text{Carbonic.}\\\text{Anhydride.}}}{CO_2} + \underset{\text{Ammonia.}}{2NH_3} - \underset{\text{Water.}}{3H_2O} = \underset{\text{Parabanic acid.}}{C_3H_2N_2O_3}$$

$$\underset{\text{Oxalic acid.}}{2C_2H_2O_4} + \underset{\text{Formic acid.}}{CH_2O_2} + \underset{\text{Ammonia.}}{4NH_3} - \underset{\text{Water.}}{7H_2O} = \underset{\text{Uric acid.}}{C_5H_4N_4O_3}$$

$$\underset{\text{Oxalic acid.}}{C_2H_2O_4} + \underset{\text{Formic acid.}}{CH_2O_2} + \underset{\substack{\text{Carbonic.}\\\text{Anhydride.}}}{CO_2} + \underset{\text{Ammonia.}}{4NH_3} - \underset{\text{Water.}}{5H_2O} = \underset{\text{Allantoin.}}{C_4H_6N_4O_3}$$

2. *Adipic acid* has been prepared by the action of nitric acid upon suet. None of the other acids of this series have been found in the human body.

The fatty acids are physiologically important, 1st, On account of their adhesive affinities ; 2d, by developing heat in consequence of their property of oxidising at a low temperature, forming carbonic acid and water, which, if too abundant, are readily removed from the system ; and, 3d, by their power of conducting heat. Although we daily consume a large amount of these acids, yet they are not excreted as such, nor do they form fats.

Glycerin. $C_3H_8O_3$.—This is the other substance which is produced in the process of saponification. It does not exist ready formed in fats, but is produced from them, together with a fatty acid, by addition of the elements of water. Glycerin is really a triatomic alcohol, and bears the same relation to the fats, stearin and olein, &c., as alcohol bears to the compound ethers, one, two, or three of the atoms of hydrogen being replaceable by acid radicles, producing fatty or oily compounds. It is an uncrystallisable, syrupy liquid,—colourless, inodorous, sweet, neutral. It dissolves in water, in alcohol, and in chloroform, but not in ether.

ORIGIN OF FAT.—The origin of fat in animal bodies has given rise to considerable discussion. 1st, It may enter the body ready formed in the food, whether animal or vegetable ; 2d, Animals seem to have the power of transforming various substances into fat. Geese fed on grain become fat, bees form wax, a species of fat, from flowers. Thus, says Liebig, the herbs and roots consumed by the cow contain no butter ; in the hay and fodder of oxen, no beef-suet exists ; and no hog's lard can be found in the potatoes given to swine. The masses of fat found in the bodies of these animals are formed in their organism, and this, according to Liebig, takes place by non-nitrogenous substances yielding up their oxygen. Dumas, however, states that the Indian corn or maize on which a goose is fed contains 9 per cent. of fat, and on calculating the quantity consumed, he found more fat in it than was sufficient to explain the increased weight of the goose. These conclusions were confirmed by the careful and extensive observations of Boussingault. Liebig, however, to support his position, made several very ingenious experiments upon swine. He says that three pigs, to be fattened in thirteen weeks, require 1000 lbs. of pease, and 6825 lbs. of boiled potatoes. These contain together 26 lbs. of fat,—21 lb. in the pease, and 5 lb. in the potatoes. One fattened pig gives on an average 50 to 55 lbs. of fat ; that is, the three together, 150 to 165 lbs. Each animal, before being fattened, contains, on an average, 18 lbs. of fat ; that is, 54 lbs. for the three. If to these 54 lbs. we add 26 lbs. from the food, we get 80 lbs ; and if we substract these from 150 lbs. to 165 lbs., there is a remainder of 70 to 85 lbs. of fat produced from the starch, &c., contained in the food. These experiments have been confirmed by the more recent researches of Messrs Lawes and Gilbert,* who found that, in fattening pigs, for every 100 parts of fat in the food, the animals stored up from 400 to 450 parts of fat in their bodies. The origin of fat, therefore, in the living body is threefold,—1st, It is derived ready formed from plants ; 2d, It is formed in the absence of oxygen, or where oxygen is deficient, by the deoxidation of starch, gum, and sugar, which thus supplies the oxygen wanted; and, 3d, By decomposition of the albuminous compounds, the actual character of which is not yet clearly ascertained.

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* Lawes and Gilbert. *Philosoph. Trans.* 1859, p. 543.

2. AMYLOID SUBSTANCES AND SUGARS.—The non-nitrogenous substances which, by yielding up oxygen, become transformed into fatty compounds, or are nearly related in chemical composition to fatty compounds, are as follows:—Glycogen, starch, and the different varieties of sugar.

1. *Glycogen.* $C_6H_{10}O_5$.—Animal starch, animal dextrin, hepatin. This substance, isomeric with starch, occurs in the liver and in the placenta, and is believed to enter largely into the composition of the tissues of the embryo. It occurs in three forms, of which one, of the formula $C_6H_{10}O_5$, is powdery, two others, $C_6H_{12}O_6$ and $C_6H_{14}O_7$, are gummy. It is easily prepared by making a decoction of fresh liver, filtering, and precipitating the filtrate with alcohol of 38 to 40 per cent. When dried, it is a white, mealy powder, neutral, inodorous, and tastes like starch. It polarizes to the right four times more intensely than dextrose sugar. Iodine colours it violet or bright brown-red, seldom pure blue. All re-agents which transform starch into sugar similarly affect glycogen, and the sugar so produced is identical with grape sugar. The ferments of the saliva, liver, and pancreas readily effect this transformation. The important physiological relations of this substance, as discovered by the labours of Bernard, Pavy, M'Donnell, Harley, &c., will be fully considered when treating of the functions of the liver.

2. *Starch.* $C_6H_{10}O_5$.—True starch is now known to exist as a constituent of the human body. (Busk, Carter.) Many of the granules, however, termed *corpora amylaceæ*, found in the brain, spinal cord, liver, spleen, kidneys, and mucous membranes, though resembling starch corpuscles in form, do not give a blue reaction with iodine, even with the addition of a little sulphuric acid, and differ from it in chemical composition. To such bodies I have for a long time given the name of *amyloid*. Starch is of great physiological importance, inasmuch as it constitutes a large proportion of human food. Infusions of almost any of the animal tissues, and saliva, and pancreatic juice, readily convert it into sugar.

3. *Sugars.*—Under this name are included a number of

organic compounds, which are soluble in water, crystallisable, have a sweet taste, neutral reaction, and in a state of solution rotate the plane of vibration of a ray of polarised light. Those of interest to the physiologist are, *a.* Saccharose, or cane sugar ; *b.* Lactose, or milk sugar; *c.* Glucose, or grape sugar ; and, *d.* Inosite, or muscle sugar.

a. Saccharose, or Cane Sugar. $C_{12}H_{22}O_{11}$.—This substance is not found in the animal body, but it is widely diffused in the vegetable kingdom, and forms an important element in the food of man. It crystallises in large monoclinic prisms, is soluble in water, insoluble in alcohol and ether, and the aqueous solution turns the ray of polarised light to the right.

b. Lactose, or Milk Sugar. $C_{12}H_{22}O_{11}$.—This sugar is found only in the milk of the mammalia. It may be obtained from milk by precipitating the casein by acid or rennet, filtering, and evaporating the whey to the crystallising point. It occurs as hemihedric trimetric crystals, and the aqueous solution turns the plane of polarised light to the right. It differs from cane sugar in crystalline form.

c. Glucose, or Grape Sugar. Diabetic sugar, sugar of urine, &c., $C_6H_{12}O_6+H_2O$.—This substance exists in the liver, in the amniotic and allantoic fluids, in the blood, in the chyle, and in eggs. In the disease called diabetes this sugar is found in the urine often to the amount of 8 or 10 per cent. ; and according to Bence Jones it exists in minute quantity even in healthy urine. Compounds of glucose are likewise found in the animal body. When gelatin, hyaline cartilage, and rib-cartilage are boiled with hydrochloric acid, large quantities of glucose are obtained. It may be obtained by evaporating the urine of diabetic patients, and may be purified by re-crystallisation from a solution in boiling alcohol. From an aqueous solution it is deposited in white, opaque, granular, hemispherical masses, consisting of the hydrate, $C_6H_{12}O_6+H_2O$. ; but from nearly absolute alcohol it is obtained as anhydrous, microscopic, sharply defined needles. It is less soluble in water than cane sugar, and it rotates the plane of polarised light 53·2° to the right. It gives a dark brown colour with liquor potassæ (Moore's test), and has the power of immediately reducing cuprous oxide from an alkaline solution of cupric sulphate (Trommer's test). Its quantitative estimation is made by the amount of cuprous oxide thrown down from a known measure of potassio-tartrate of copper (Fehling's test). The potassio-tartrate of copper, made alkaline by the addition of a little liquor potassæ, is heated to boiling in a capsule, and the liquid containing sugar is dropped in until the copper solution acquires a pale straw colour by the separation of red cuprous oxide.

d. Inosite, or Muscle Sugar. $C_6H_{12}O_6$ (Pl. I. fig. 16).—This substance, isomeric with glucose, exists in the muscular substance of the heart, in the lungs, kidney, liver, and spleen. It is best prepared from the muscle of the heart. It crystallises in tabular plates, or oblique prisms, or right rhombic prisms, containing two atoms of water of crystallisation. Inosite has a sweet taste, and no rotatory power, differing in the latter respect from the other sugars.

3. Acids related to Sugar.—Nearly allied to the starch and sugar group of compounds just described are the two substances known as lactic and sarcolactic acids, the former existing in sour milk, the latter in muscle-juice.

1. *Lactic acid.* $C_3H_6O_3$.—This acid is the result of a peculiar fermentation, the lactic acid fermentation, of various kinds of sugar, preceding the butyric acid fermentation. The change of milk sugar into lactic acid is shewn by the following equation:—

$$\underset{\text{Milk sugar.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Lactic acid.}}{4C_3H_6O_3}$$

2. *Sarcolactic acid.*—When this acid was discovered by Berzelius in the juice of muscular flesh, he imagined it to be identical with the lactic acid of sour milk, but Liebig shewed that though the acids are hardly to be distinguished, their calcium and zinc salts exhibit marked distinctions. This acid gives the acid reaction exhibited by muscle after it has been fatigued by contractions induced in any way.

3. The Mineral Principles.

The mineral or inorganic principles found in the human body may be classified as follows:—

1. Gases.—*Oxygen* (O) and *nitrogen* (N) exist in a free state in the blood and in the urine.

Hydrogen (H) is never found in a free state, but exists in water, and in light carburetted hydrogen (CH_4).

Light carburetted hydrogen (CH_4) has been found along with other gases in the flatus from the intestinal canal.

2. Free Acids.—*Carbonic acid* (CO_2), or as it is now called, carbonic anhydride, exists in both venous and arterial blood, especially in the latter.

Sulphuric acid (H_2SO_4) does not exist free in the body, but forms sulphates, which may be either neutral or acid, by combining with various bases.

Silicic acid (SiO_2) has been found in several tissues.

Hydrochloric acid (HCl) occurs in a free state in the gastric juice.

3. Salts.—1. *Carbonates.—Sodium carbonate* ($Na_2CO_3+10H_2O$) and *potassium carbonate* (K_2CO_3) exist in urine, and probably in the blood and tissues. *Ammonium carbonate* (NH_4HCO_3) is said to be found in expired air, but as a normal product, its presence is doubtful. *Calcium carbonate* ($CaCO_3$) exists in the bones and teeth, and it also occurs as a urinary sediment. In the urine of man it is very rare, but is common in that of the horse, where it forms peculiar globular bodies, identical with the artificial calculi made by Mr Rainey, which will be described in treating of the molecular elements of the tissues. *Magnesium carbonate* ($MgCO_3$) also exists in bones, teeth, and urine.

2. *Chlorides.*—The *chlorides of sodium* (NaCl) and *potassium* (KCl) exist in large quantity in all the solids and fluids of the body. Sodium chloride is the more abundant of the two. Potassium chloride is found chiefly in muscle-juice. *Ammonium chloride* (NH_4Cl) is found in the saliva, in tears, and in the urine.

3. *Oxalates.—The oxalate of calcium* (CaC_2O_4) is found in the urine in certain states of the system. It forms octahedral crystals and dumb-bells (Pl. I. fig. 17).

4. *Fluorides.—Fluoride of Calcium* (CaFl) exists in small quantity in bones, in teeth, and in the blood. It is found chiefly in enamel, which owes its great hardness to this salt.

5. *Phosphates.*—The *phosphates of sodium* are found in all the solids and fluids of the body. They are three in number, the basic ($Na_3PO_4+12H_2O$), the neutral ($Na_2HPO_4+12H_2O$), and the acid ($NaH_2PO_4+H_2O$). They exist largely in the blood, and recent investigations shew that in the process of respiration they carry the carbonic acid, in a loose state of combination, from the tissues to the lungs, there to be eliminated. In like manner, the basic *phosphate of potassium* ($K_3PO_4+12H_2O$), the neutral ($K_2HPO_4+12H_2O$), and the acid ($KH_2PO_4+H_2O$) are found in every part of the body. The neutral, or tribasic *phosphate of*

calcium ($Ca_3 2PO_4$) forms the chief part of the earthy matter of bone. It exists in considerable quantity in teeth, and is found in all the solids and fluids of the body. The *phosphate of magnesium* ($HMgPO_4+7H_2O$), exists in the blood, in the urine, and generally, though to a comparatively small amount, in the tissues. The *ammonia-magnesic phosphate* ($MgNH_4PO_4+6H_2O$) is frequently met with as a constituent of urinary calculi, and is always formed during the alkaline fermentation of urine. It occurs as large, transparent, rhombic prisms, but it is sometimes peniform or feathery in its appearance (Pl. I. fig. 18).

6. *Sulphates.*—The *sulphates of sodium* ($Na_2SO_4+10H_2O$), of *potassium* (K_2SO_4), and of *calcium* ($CaSO_4$), are found everywhere, specially in the blood and urine. *Sulphate of calcium* exists largely in bone.

7. *Sulphocyanides.*—The *sulphocyanide of potassium* ($KCNS$) is found only in the saliva, and in very small quantity.

4. METALS.—The presence of iron, manganese, copper, and lead have been already noticed (p. 5). The state of combination in which these metals exist in the body is quite unknown. Of these, iron is the most important.

The mineral ingredients above described enter the body of man in his food and drink. They all exist, more or less, in the ordinary articles of food ; and even pure water, the natural drink of man, contains many of them in a state of solution. For instance, if a man were to consume two lbs. of potatoes and two lbs. of bread daily, no less than half an ounce of solid tribasic phosphate of calcium would enter his system in twenty-four hours. The salts are chiefly excreted by the kidneys and alvine evacuations, but every secretion contains more or less of them, so that it is possible to judge of the amount of mineral matter which enters the frame from the quantity which leaves it. They are given off by the emunctories in proportion to the amount introduced, so that a healthy state of the economy is preserved. Some mineral substances pass through the body and appear in the urine unchanged, such as the alkaline carbonates, sulphates, nitrates, phosphates, borates, chlorates, silicates, &c. ; while others are changed, such as salts of ammonia, which may be converted into nitrates. The neutral salts of the organic acids are converted into carbonates.

Irregularities of food must modify the amount of mineral matter taken into the system. These mineral matters are usually soluble, but only to a certain extent. If then they be in excess, so that the natural fluid containing them is more than saturated, they are partly precipitated and give rise to concretions. A diminution of the fluid of the secretion would of course produce the same result. Occasionally, insoluble salts are formed, which are deposited from one or other of the excretions, an example of which is seen in the octahedral crystals of oxalate of lime found in the urine.

5. WATER (H_2O) forms 70 per cent. of the whole body. It is an important constituent of all the solids and fluids. It is chiefly derived from without, in the food or drink, but a small quantity is formed within the body by the oxidation of the hydrogen of organic compounds.

4. PIGMENTARY PRINCIPLES.

In animals, colour depends on two circumstances: first, the deposition of pigment; and, second, on purely optical phenomena, originating in peculiarity of structure. Of some insects, as the cochineal-insect, *Coccus cacti*, the entire substance is used as a dye; certain of the animal fluids, as the blood, bile, and urine are also strongly coloured. Pigments rarely exist in animals in the separate state, and their separation is a matter of great difficulty.

Pigment exists more or less in the rete mucosum of the skin of all races of men, and its amount and character determines the colour peculiar to each race. In the negro race, black pigment abounds; in the Indian, red; the Malay, yellow or brown; and so on. In proportion as the race is more and more fair, the individual varieties of complexion due to this cause are more pronounced. Thus, there is often a more striking difference between the complexion of two individuals, Europeans, than can be found between two negroes. Occasionally, individuals of white races are met with having an unusually large amount of pigment in the skin, either generally diffused, or located in one or more spots. A black pigment is also found in the lungs of old persons, and in those working in coal mines, or living in a mining district. The nature of the cutaneous pigment found in man has still to be examined, but in the lungs it consists of pure carbon.

Black pigment, termed *melanin*, is found in the cells of the choroid of the eye. This pigment (melanin) (Pl. I. fig. 24), and the black pigment found in a cancerous tumour, have been analysed by Scherer, Rosow, and Heintz, with the following result :

Melanin of the choroid.				*Melanin of tumour.*	
Scherer.		Rosow.		Heintz.	
C.	58.28	C.	54.0	C.	53.44
H.	5.92	H.	5.3	H.	4.02
N.	13.77	N.	10.1	N.	7.1
O.	22.03	O.	30.0	O.	35.44
		Ash	0.6		
	100.00		100.0		100.00

We shall now describe, 1. The pigments of the blood ; 2. The pigments of the bile ; and, 3. The pigment of the urine.

1. THE COLOURING MATTER OF THE BLOOD.—The colouring matter or pigment of the blood has received various names, Hæmoglobin, Hæmato-crystallin, and Cruorin. The terms, hæmatin and hæmatoidin, are now restricted to those crystals which are produced by physiological agencies, in clots formed by the effusion of blood into the cavities or tissues of the body.

1. *Hæmato-crystallin, or Hæmoglobin* (Plate I. figs. 19, 20, 22), as already mentioned, is the most complex substance found in the body. It is represented, according to Thudicum, by the formula $C_{600}H_{960}N_{154}FeS_3O_{177}$. It may be obtained in a crystalline form by adding water, ether, chloroform, or alcohol, to a drop of blood on a slide of glass, covering it over with a thin covering glass, allowing it to stand for one or two hours, and then examining under the microscope. Lehmann obtained it by passing a slow stream of oxygen through a mixture of blood and water for fifteen minutes, then a stream of carbonic acid till the fluid becomes bright red, when the hæmato-crystallin, crystallises out. The form of the crystals varies in different animals—being prismatic in man and most mammalia, tetrahedrons in the rat, mouse, and guinea-pig (fig. 22), hexagon tablets in the squirrel, and rhombohedrons in the marmot. The crystals are made black by nitric acid, and decolorised by chlorine. Hæmato-crystallin contains,

as proximate constituents, an albuminous body, which is colourless; and hæmatin, which is coloured, and retains the iron of the original substance. According to Hoppe-Seyler* and Stokes,† hæmato-crystallin exists in the blood in two forms, the one called *hæmoglobin* (Hoppe-Seyler) or purple cruorin (Stokes), the other *oxy-haemoglobin* (Hoppe-Seyler) or scarlet cruorin (Stokes), differing from the first in having a certain amount of oxygen in loose combination. The spectroscope affords the only means of distinguishing between these modifications. When a thin layer of arterial blood mixed with water is examined by the spectroscope, two dark and sharply defined absorption bands are seen between D and E, one close to D, the other and thicker one close to E; if D is at 80 of the scale, and E at 106, the first band runs from 81 to 87, the other from 95 to 106. This is the spectrum of oxy-hæmoglobin. But if the solution is treated with any reducing agent, depriving it of its oxygen, such as ferrous sulphate, it assumes a purple colour; and when again examined, it will be found that the two absorption bands have disappeared, and only one band, stretching from 82 to 97, is to be seen. This is the spectrum of hæmoglobin. Since ordinary venous blood always contains some oxygen, the spectrum usually seen, of course, is that of oxy-hæmoglobin (two bands); but the blood of an animal dying of asphyxia, in which there is no oxygen, always shews the single absorption band of hæmoglobin (Hoppe-Seyler).

2. *Hæmatin or Hæmatoidin*—$C_{14}H_{18}N_2O_3Fe$ (Plate I. fig. 21)—is a crystalline substance often found in extravasated blood. It is produced by the decomposition of hæmatocrystallin into an albuminous body and hæmatin. It is sometimes amorphous in little grains or globules, sometimes in small crystals belonging to the monoclinic system. It is transparent, strongly refracting, yellowish red or ruby red, insoluble in all ordinary reagents, except potash. Iron is always found in this substance.

2. THE COLOURING MATTERS OF THE BILE.—Five distinct pigments have been found in the bile of man and other mammalia, namely, Bilirubin, Biliphæin, Biliverdin, Bilifuscin, and Biliprasin. (Plate I. fig. 23.)

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* Hoppe-Seyler, *Virchow's Archiv.* xxxiii. 446, xxix. 223 and 597; *Med. Centralbl.* 1864, p. 817; Handbuch. Chem. Anal. 1870.

† Stokes, Proced. Royal Society, xiii. 355.

1. *Bilirubin.* $C_{16}H_{18}N_2O_3$.—This substance constitutes the chief pigment in the bile of man. It may be extracted from gall stones by chloroform. It consists, when obtained pure, of minute amorphous granules, of a pure red colour, like nitric oxide of mercury (Pl. I. fig. 23). When precipitated by alcohol, it shews minute yellow rhombic prisms. By oxidation with nitric acid, this substance is converted into biliverdine, giving a beautiful play of colours, first green, then blue, purple, violet, and, lastly, a dull red or brownish yellow, affording a test for very small quantities of bile in the urine.

2. *Biliphæin or Cholophæin.* $C_{16}H_{18}N_2O_3$ (?)—According to Dr Thudicum, this pigment is probably a modification of bilirubin, at least it is intimately related to it. It is obtained from gall stones, like bilirubin, by the solvent action of chloroform and alcohol, but at a later stage of the process. It is always crystalline, thus differing from bilirubin. The crystals have a dark, reddish brown colour, and belong to the rhombic system, being prisms with obtuse angles.

3. *Biliverdin.* $C_{16}H_{20}N_2O_5$.—Though found only in small quantity in the bile of man, it is the chief pigment in the bile of herbivorous animals. It is obtained by the oxidation of bilirubin. When bilirubin is dissolved in caustic potash and exposed to the air, it becomes gradually green. On addition of hydrochloric acid, biliverdin is thrown down in flakes. It is soluble in alcohol, giving a beautiful green solution. It cannot be retransformed by any known chemical process into bilirubin or biliphæin. Dr Thudicum has devised a new test for this substance. On boiling an alcoholic solution of biliverdin with caustic ammonia and silver nitrate, a reduction of the dissolved silver oxide is observed. On the addition of a mineral acid, a splendid purple colour is produced, due to the formation, by oxidation, of a new compound, termed bilipurpurin.

4. *Bilifuscin* ($C_{16}H_{20}N_2O_4$) and 5. *Biliprasin* ($C_{16}H_{22}N_2O_6$) have both been found to a very small amount in human gall stones by Staedeler. They are black, glossy, brittle, non-crystalline substances. An alcoholic solution of bilifuscin is of a light brown colour, while that of biliprasin is green. They are not of much importance to the physiologist.

Spectrum analysis has not yet afforded any definite results as regards the bile pigments. The spectrum of biliverdin shews a very brilliant red.

3. The Colouring Matters of the Urine.—Although large quantities of urine have been carefully analysed by various eminent physiological chemists, the state of knowledge regarding the pigments is very indefinite. It is probable that in human urine three pigments exist, namely, urohæmatin (Harley), urochrome (Thudicum), and uroxanthin (Heller), or Indican (Schunk).

1. *Urohæmatin.*—This substance is a dark red amorphous mass, resinous in consistence, containing iron, readily soluble in ether, alcohol, alkalies, and fresh urine, but insoluble in water and acids. Harley—who isolated this substance by a very complex process, which it would be out of the province of this work to describe—regards all the other pigments discovered by other chemists as derivatives of urohæmatin.

2. *Urochrome.*—Dr Thudicum extracted from a large amount of urine, an amorphous, yellowish substance, easily soluble in water and acids, less so in ether, and least of all in alcohol (thus differing in a marked degree from Harley's urohæmatin), to which he gave the name of urochrome. According to this chemist, urochrome yields, by decomposition, a purplish-black matter, insoluble in water, and very slightly soluble in alcohol, called *uromelanin.* Uromelanin does not exist, as such, in the urine, but is derived from urochrome. The urochrome, however, does not immediately yield uromelanin, but a less oxidised substance, of a light yellow colour, which, however, becomes brown on exposure to air, and in course of time is precipitated as a perfectly black pigment. The composition of this black pigment is $C_{36}H_{43}N_7O_{10}$, very similar to that of the black pigment (melanin) found in the choroid of the eye, and in melanotic cancers. Taking into consideration the very high atomic weight of this substance (733), Dr Thudicum believes that it may possibly be derived from hæmato-crystallin, the crystallisable compound of the blood corpuscles, which, as already explained (p. 32), may be split into an albuminous body, and into hæmatin. According to this view, uromelanin would be a derivative of hæmato-crystallin, as uric acid is a derivative of albumin.

3. *Uroxanthin or Indican.* $C_{26}H_{31}NO_{17}$. — This substance occurs in human urine, both healthy and diseased; and when present in considerable quantity, causes the urine, after spontaneous fermentation, or on addition of acids, to deposit sometimes indigo-blue (uroglaucin of Heller) or indigo-red (urorhodin of Heller). It may be detected by precipitating the urine with

basic acetate of lead, collecting the precipitate which forms in the filtrate on addition of ammonia, and decomposing it with cold dilute acids ; the filtrate then depositing, first, indigo-blue, then indigo-red, and afterwards other products of the decomposition of indican. Thudicum, however, denies the presence of indican in the urine.

The chemical constitution of the various tissues, such as muscle, nerve, tooth, bone, &c., the analyses of the different fluids, secretions, and excretions, such as the blood, bile, saliva, gastric juice, urine, fœces, &c., and the chemistry of the great functions, such as digestion, respiration, nutrition, &c., will be hereafter described.

GENERAL HISTOLOGY.

The ultimate elements of the tissues have been variously classified. We shall consider them under four heads : 1st, the molecular ; 2d, the cellular ; 3d, the fibrous ; and 4th, the tubular elements of the tissues,—concluding with a consideration of the general doctrines of their origin and development.

THE MOLECULAR ELEMENTS OF THE TISSUES.

Definition.—By a histological *molecule* is to be understood a minute body, seen under high magnifying powers in all organic fluids and textures, varying in size from the four thousandth of an inch down to a scarcely visible point, which may be calculated at less than the twenty thousandth of an inch in diameter. Optically it is distinguished according to its size ; the smallest presenting dark or light points as the focus is changed, and the larger exhibiting a dark or light centre, surrounded by a distinctly shadowed ring. These last are frequently distinguished by the name of *granules.* The ultimate molecule has never been reached, even with the highest magnifying powers. In the same manner that the astronomer with his telescope resolves nebulæ into clusters of stars, and sees other nebulæ beyond them, so the histologist with his microscope magnifies molecules into granules, and sees further molecules come into view.

The chemical composition of molecules must vary infinitely, but I have been in the habit of classifying them into four groups, and referring them to—1st, the albuminous ; 2d, the fatty ; 3d, the mineral ; and 4th, the pigmentary compounds. These component constituents may be mingled together in various proportions, so as to produce simple and compound molecules.

Physical properties.—In the vast majority of cases they are globular in shape, but they may be angular, square, and of various forms. They may differ in size, or be of tolerably uniform size in the same liquid or substance. They may be regularly or irregularly diffused in the matter examined. Sometimes they are concentrated in particular places, and at others scattered in groups (Pl. II. *a*, *b*, *c*, *d*). Their colour is various. Most of the pigments in plants and animals are dependent on the formation of molecules, which in the human lung have been proved to be pure carbon ; and in the tissues of plants and animals, differently tinted kinds of fat or of wax.

Development of molecules.—Molecules may be formed in two different ways—1st, by precipitation in fluids or semi-solid substances ; 2d, by the disintegration of previously formed tissues. The former may be called *histogenetic* (ιστος and γενος), and the latter *histolytic* (ιστος and λυσις—dissolutio)—a term first proposed by Dr Lyons, of Dublin. They may be also denominated molecules of formation and molecules of disintegration.

Histogenetic molecules are formed either from the union of two simple organic fluids, or from precipitation occurring in formative fluids holding various substances in solution. It was Dr Ascherson, of Berlin, who first discovered, in 1840, the important fact that the mere contact of oil and fluid albumin caused the latter to coagulate in the form of a membrane, which he called the haptogen membrane, from ἁπτωμαι, to come in contact. A more complete mixture of two such drops produces, as is well known, a white opaque fluid or emulsion, which structurally exactly resembles milk—that is to say, it consists of molecules composed of a drop of oil surrounded by a layer or membrane of coagulated albumin. Such compound molecules possessing the property of endosmose may therefore readily be produced artificially, and by trituration can be reduced in size, so as to resemble the elementary molecules in chyle or in the yolk of the egg. If oil and albumin be introduced into the stomach and intestinal canal, they are always so reduced ; and one of the objects of digestion would appear to be, separating from the food and rendering fluid its oil and albumin, so as to produce the chyle molecules, which are ultimately transformed into blood. Indeed, everywhere in living organisms it may be observed that oil and albumin, formed as secretions by plants, and entering the bodies of animals as food, either separately or united, constitute the chief origin of molecular formations.

Mr Rainey pointed out the condition which causes molecular mineral matter to assume the form of rounded nuclear bodies.* This condition is viscosity. If carbonate of lime be dissolved in water, the forms produced on its precipitation are crystalline, but if the the fluid be glutinous—composed, for example, of fluid gelatin or gum—the forms produced are oval or globular. Precipitations made in this way on slides of glass, closely resemble the appearances called nuclear or cellular in different stages of development, as in Pl. II. fig. 3. By allowing a drop of the watery and a drop of the gummy solution of carbonate of lime to come in contact, it may be shewn how the crystalline gradually passes into the rounded nuclear forms (Pl. II. fig. 4.) Mr Rainey has further shewn how starch granules are produced in the juices of vegetables, by the endosmose of gum into a cell containing a solution of dextrin.† In the same manner that the contact of oil and albumin produces oleo-albuminous molecules, so does the contact of gum and dextrin precipitate starch molecules. In this manner we can comprehend how the mixture of various organic fluids gives rises to particles of different kinds.

Histolytic molecules are the result of the transformation and disintegration of fluid and solid substances, by chemical or mechanical action. They are often larger in size than histogenetic molecules, are more purely fatty, and from being sometimes associated with the *dêbris* of broken-down texture, may, in such cases, be readily distinguished (Plate II. fig. 1, *d*). Thus, in the breaking up of cells or of muscle, when they become fatty, or in the putrefaction of animal or vegetable matters, these may be seen to soften, lose their peculiar structure, break up, and ultimately be reduced to a molecular condition.

We shall subsequently see that these two kinds of molecules are constantly changing places ; or, in other words, molecular matter formed from the process of disintegration, may, when placed under peculiar circumstances, become the basis of matter which undergoes development. In nature, the breaking down of one substance is the necessary step to the formation of another, and the histolytic or disintegrative molecules of one period become the histogenetic or formative molecules of another. This fact constitutes the basis of the law, which I shall subsequently seek to establish.

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* On the Mode of Formation of Shells of Animals, of Bone, and of several other Structures, by a process of Molecular Coalescence, &c. By Geo. Rainey, M.R.C.S. London, 1858.

† Microscopical Journal, 1858.

That histolytic molecules are capable of arranging themselves into all forms, admits of demonstration. In an old preparation of areolar tissue, mounted in spirit, in my possession, innumerable fatty molecules have been precipitated on the glass, which have arranged themselves as represented (Plate II. fig. 2). In other molecular masses in the same preparation, round spaces or vacuoles have formed themselves. I have seen exactly the same arrangement and structure in the earliest formative stage of vegetable mould.

Molecular movements.—These molecules are governed by forces which induce among them a variety of movements, and cause them to combine in definite ways. This force, which we may call *molecular force*, is altogether independent of cell, nucleus or other form of structure.

1. There are the molecular movements described by Robert Brown—hence called *Brunonian* movements. These vibratile, circular, serpentine, or irregular motions, may be observed whenever molecules are suspended in fluids of certain densities, but are too well known to require notice here. They occur altogether independent of organised structures, and must be regarded as in their nature purely physical.

2. The peculiar movements observed in the interior of cells, vegetable or animal. Amongst these I may refer to those seen in the large vegetable cells of the *Chara*, *Vallisneria*, and *Tradescantia* amongst plants, and those of chyle, the yolk of the egg, and of the salivary cell amongst animals. It has been much disputed whether this class of molecular motions be physical or vital.

3. I have frequently watched the formation of vibriones in putrid fluids. A scum, composed of molecules, collects on the surface : gradually several of them unite in minute filaments, more or less long, which assume vibratile or serpentine movements, and move in various directions across the field of the microscope. Such movements must be vital.

4. Other movements, which are unquestionably vital, occur

in the molecules of the yelk, on the entrance into the ovum of the spermatozoid. Here it cannot be maintained that the results are purely physical, because in different ova we see such widely varying effects from apparently the same cause. Neither can it be attributed to any direct influence of the cell, or of its nucleus—the germinal vesicle. For example, an egg is fully maturated in the female organs of generation, and would prove abortive if a spermatozoid did not find its way through the zona-pellucida, and get amongst the molecules of the yolk. As soon as it does so, the apparently purposeless Brunonian movements receive a new impulse and direction. Both spermatozoid and germinal vesicle are dissolved among them, and that wonderful phenomenon of the division of the yelk takes place, not by cleavage or other action of the cell-wall or nucleus, but by the separation of the mass into two masses instead of one. The nature of the phenomenon in this case may be compared to what is observable in a dense crowd of men called upon to pass over to the right or left hand in order to settle any disputed question by a majority. At first unusual confusion is communicated to the whole ; some hurry in one direction, others in another ; but after a time there is seen at the margins, where the crowd is least dense, a clear space, which gradually approaches the centre, and at length bisecting the whole, produces a complete segregation of the crowd into two portions. So with the molecules of the yelk in the egg after impregnation : their movements are directed by conditions which did not previously exist, and a stimulus is imparted to them which causes the peculiar result. It is the division and sub-division of the yelk, wholly or in part, which produces the germinal mass out of which the embryo is formed, and this not by any direct influence of the cell or nucleus, but in consequence of a power inherent in the molecules themselves, which was communicated to them for a specific purpose.

5. The peculiar movements so well described by Brücke, Von Wittich, Harless, and especially by Mr Lister, in the pigment cells of the frog's skin,* and which occasion the sudden change of colour in the chameleon, in fishes, and numerous other animals. The black pigment molecules may be diffused throughout the cell or concentrated in a mass, and all kinds of

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* On the Cutaneous Pigmentary System of the Frog.—*Philosophical Transactions,* 1858.

intermediate gradations may exist between diffusion and concentration. The change in colour is owing to these alterations in the molecules, the tint being light when they are concentrated, and dark when they are diffused. Mr Lister ascertained by experiment that their concentration is caused by exposure to light, by death of the animal, and by sudden section of the nerve going to the skin ; while darkness and irritation of the nerve or skin cause diffusion. Sudden amputation of a limb produced at first diffusion, followed by the concentration of death. These movements of the pigment molecules are peculiarly vital, and altogether independent of the cell-wall or nucleus. The former is stationary, and acts only as a sac or investing membrane around the moving particles, while the concentration of them about the nucleus is purely accidental, and frequently occurs in other parts of the cell. I have seen these molecules myself, as Mr Lister describes them, streaming out to and returning from the circumference under the influence of the stimuli referred to, where no cell nor nuclear action could be thought of (Plate II. figs. 13 to 16).

6. There are many other kinds of movements which are evidently unconnected with cells : for example, the contractile fibrillæ of muscle are not dependent for their inherent power on cells or other form of structure, but on the square-shaped molecules of which its substance is composed (Plate IV. figs. 24, 25). The same may be said of the movements observed in the amæba, in pus, mucous and colourless blood cells, as well as in other viscous masses, and which are now generally denominated *amœbiform*.

All these phenomena are connected with the molecules themselves ; the force occasioning them is a molecular force, and has nothing to do with pre-existing cells, or supposed germinal centres, as some have imagined. Further, there can be no doubt that some of these actions are in their nature purely physical, whilst others are peculiar to living beings, and therefore vital. We have, therefore, to determine, if possible, what are the physical and what are the vital laws of molecular coalescence and disintegration.

Physical law of molecular coalescence and disintegration.—The power of combination between two molecules, which, under peculiar conditions, not only move, but so move as to advance towards and press upon each other, that they at length unite and produce higher forms, must be attributed to a molecular force, operating in obedience to fixed laws. Thus it was demonstrated by Newton, that in a sphere the total attraction resulting from the particular attraction of all its component parts, is, as regards any body drawn towards it, the same as if they had been concentrated at the centre. Hence minute spherical particles, as so many gravitating points, will be drawn towards each other with a force varying inversely as the squares of the distances between their respective centres. Molecules, therefore, occurring in a fluid medium of equal density, or nearly so, will, by their mutual attraction alone, form themselves into spherical collections or masses. But when two spherules unite to form a larger one, they must each first disintegrate. In other words, they must both fall into pieces, and afterwards be put together under the same static conditions as they were before (Plate II. fig. 17).

When bodies assume the dumb-bell or elliptical form, perfect coalescence of two globules has not taken place. Under these circumstances, the molecules, in a mass contained in the inner hemispheres, coming within the attractive influence of both spherules, are simultaneously drawn in the direction of their centres by two variable forces, whose sum is always a constant quantity, as shewn in the diagram (Plate II. fig. 19). Here the axis major is A B, and the axis minor C D. The foci are the points c and c' which are the centres of the coalescing spherules, and the co-ordinates of the curve over the lines $c\,p$ and $c'\,p$. The coalescence of two such spherules will cause the dumb-bell shape gradually to disappear, and the spherical form of the remote hemispheres to be changed into that of an ellipse, so that at length the exterior outline also becomes elliptical, and there results a form presenting two ellipses, one situated within the other (Plate II. fig. 3, *a*). The still further coalescence of two sphericle particles, would end in two perfect spheres, one inside the other (fig. 3, *b*).

The appearance of a nucleus in these bodies is owing to their possessing different degrees of density. In fact, formed as they are under the influence of gravity, their density varies according to the degree of attraction exerted upon their particles, —an attraction which is as their distance from the centre,—the force being least at the centre, and greatest at the circumference. Hence, when looking at it by transmitted light, the object appears flat with a nucleus. The concentric lamination in the larger concretions is owing to another cause, viz., the union of successive masses, as in Pl. II. fig. 3, *b*. and fig. 5. All three stages in the formation of these bodies, namely, the collecting of the spherical particles into globular masses, the disintegration of these particles, and the final arrangement of their molecules in a laminated form, are all the effects of the same cause,—universal attraction or gravity. They are seen not only in the microscopical bodies, which have been so commonly regarded as cells, but in urinary, biliary, and intestinal calculi.

When crystalline are converted into globular forms, as in the ingenious experiments of Mr Rainey, who mixed a watery with a viscous solution of an earthy salt, he supposes that the two equal molecular masses, instead of attracting, repel each other. They will then arrange themselves in a spherical form, of which the central molecule will retain its position, whilst those around it will be thrown into diverging lines or radii going from the centre. Two such groups, if now placed side by side, will have their adjacent molecules impelled in directions which intersect one another (see Pl. II. fig. 18). The point of intersection at *a* and *a'* will denote the amount of the attraction of gravitation necessary to balance the force of impulsion acting on the molecules at *a*, and so bring them into the condition of rest. A quadrilateral figure would in this way be produced, or a primitive crystal, and the shape of such crystal would vary according to the density of the fluid, the relative size of the masses, and other causes influencing the amount of attraction, at *a*, *a'*, and so varying the angle, A C B, thus forming different angular primitive crystals. Thus the straight radiating fibres from the centre to the circumference in any particular body, are in their nature crystalline, while the concentric circles are not so. Hence attracting and repellent properties may exist in one body. The whole also may be modified by chemical and electrical actions, as well as by heat, which would occupy too much space to consider here. It is sufficient for us to know that physical forces may, under different circumstances, produce crystals from limpid, and globular nucleated bodies from viscous fluids, and that the latter closely resemble those forms which have been generally considered as organic.*

It results from these observations of Mr Rainey, and from his careful investigations into the structure of shells, especially those of the lobster, crab, oyster, &c., that many forms and processes, hitherto considered as altogether owing to vitality in the tissues of plants and animals, are the result of purely physical operations. The physical law of molecular disintegration also has been made out by Mr Rainey, who shews, 1st, That spherical bodies, formed on the principle of universal attraction, in a medium of given density, become in one of greater density gradually disintegrated, and that these molecules, at first completely separated, afterwards re-arrange themselves in fresh forms. Thus the nucleated bodies (Pl. II. fig. 3) soon lose their shape when kept in glycerin, and leave a membranous organic looking structure behind of the inspissated gum. 2d. The addition of acids or chemical combinations produce similar effects. 3d. The same results occur if, when the artificial calculi are well formed, they are put into a glass well filled with the solution taken from the same bottle, and so secured from the access of air that no alteration in its density or chemical composition can take place. This last is a most important fact, shewing that the same physical power which leads to the formation of these artificial bodies, when long continued, leads to their disintegration or destruction. These changes occur slowly, and require time, but their contemplation, when regarded as purely physical phenomena, must strike us with surprise as being closely allied to our conceptions of the progress of life itself.

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* Op Cit. pp. 81-83 and 99.

Mr Bridgman of Norwich has shewn that bodies produced slowly by Mr Rainey's process, may be formed in a few hours by inserting into viscous solutions of carbonate of lime the two wires of a galvanic battery; and he further concludes from experiments, that molecular precipitation is influenced by electrical currents, so that if a tissue be in a negative state it grows, and if in a positive state it disintegrates. "To set up absorption, therefore," he says, "it is only necessary to induce an electro-positive condition of a part." Further, he has succeeded in forming artificial cartilage and bone by placing dentine in albumin or white of egg, and inserting the wires of a galvanic battery. He says:—"Around the negative pole will be found a large mass of brilliantly clear and transparent jelly. This substance, although it has been formed out of albumin only, is entirely altered in its character. It is no longer, like albumin, soluble in cold water, or coagulable by heat. It has become identical with the material of basement membrane and bone cartilage. . . . The portion formed at right angles to the two poles is of this character in its densest state, almost, if not quite, equalling the densest cartilage. An examination by the microscope shews that it is also in some parts thickly studded with peculiar globular crystals of lime, closely resembling those figured by Mr Rainey. It is thus, in its composition, strictly analogous to bone in the early stage of its calcification."*

I have examined some of Mr Bridgman's preparations, and can confirm the accuracy of his descriptions. In the section of a young horse's tooth, these nucleated bodies may be seen at the margin of the crusta petrosa, uniting with its substance to form bone (Pl. V. fig. 12). When, moreover, we compare the concentric rings and laminæ surrounding the Haversian canals, with the like arrangement existing in calculi and all concretions, there can be little doubt that the mineral deposits in bone are, in no small degree, connected with the molecular law of aggregation. Many years ago I discovered that the pellicle which forms on the surface of lime-water presents the appearance represented (Pl. II. fig. 7), and closely resembles pavement epithelium. It is evidently caused by the nucleated calcareous concretions becoming flattened, and adhering at their edges, in the same manner that epidermic cells do.

Other facts of great importance have in recent years been discovered, having relation to the physical condition of viscous matter in the animal body. Of these may be mentioned—

1. The discovery by Graham of the facility with which saline limpid solutions pass through membranes, whereas those of gum, dextrin, gelatin, albuminous substances, &c., pass through with great difficulty, or not at all. The former he named crystalloids, the latter colloids.

2. The discovery by myself of the manner the numerous hyaline or diaphanous bodies, so common in morbid products, are produced.† A glutinous matter forms within the substance of cells, which, under certain conditions, may be squeezed out of them by pressure, giving rise to a multitude of globular transparent bodies, which float loose in the field of the microscope (Pl. II. fig. 11).

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* On the absorption of bone and dentine, p. 11.

† See "Journal of Anatomy and Physiology," vol. i. p. 322. 1867.

3d. The recent experiments of Montgomery with protagon, or myelin,* a substance obtained by boiling yolk of egg with alcohol. On the addition of water, there may be seen shooting out from a mass of it under the microscope, processes which often assume a spiral form (Pl. II. fig. 8), or enlarge at their extremities to produce rounded knobs, having concentric circles (Pl. II. fig. 9). When broken down with water, albumin, glycerin, serum, or other substances, and acted upon by weak acetic or nitric acids, this substance can be made to assume the form of areolar and elastic fibres, spiral ducts, varicose nerve tubes, the broken up substance of brain and spinal cord, or nucleated cells—simple and compound, pus and cancer cells, and bodies, which, like the salivary corpuscles, exhibit numerous granules in their interior, possessing active molecular movements. (See Pl. III. fig. 29, *a b c d e.*) I have repeated these experiments of Dr Montgomery and annually shew to my practical classes the artificial cell, fibrous, and tubular forms which may be thus artificially produced. †

We see molecules, therefore, combining in the forms of crystals and nucleated spherules, and inasmuch as we have discovered the physical conditions on which they depend, and can produce them artificially, we have no difficulty in classifying these among purely physical phenomena, even when they occur in the interior of animals. But when other molecules unite to form nuclei cells, and fibres, and these arrange themselves into tissues and organs to produce plants and animals, we are ignorant of the conditions by which these results are brought about ; we cannot imitate them artificially, and we are content to call them vital. That is to say, that certain actions originate in, and are directed by, conditions which are as yet undetermined, but which, as they only occur in organic, as distinguished from inorganic bodies, constitute vital activity. Not that an organized body is independent of physical forces, but that certain influences are communicated to them, which, as invariably resulting in specific forms or properties, make up the sum of what we call vitality. These also seem to be governed by a fixed law.

The vital law of molecular coalescence and disintegration.—In endeavouring to determine the nature of vital actions impressed upon molecular matter, I have been led to the following-ing law or generalization, namely, THAT THE DEVELOPMENT AND GROWTH OF ORGANIC TISSUES, ARE OWING TO THE SUCCESSIVE FORMATION OF HISTOGENETIC AND HISTOLYTIC MOLECULES. We have already seen that development and growth in animals, originate in the molecules of the yelk of the egg, or of a germinal molecular mass, formed from organic matter. In either case it would appear that the first form is molecular; that the molecules unite to produce nuclei and cells; that these become disintegrated to produce a secondary mass of molecules; that these again unite to form secondary nuclei and cells, and that the same process is repeated more or less often in various developments, until the animal or tissue is formed. This constitutes the successive histogenetic and histolytic molecules, observable in the process of growth—the former building up to a certain extent, and the product disintegrating to produce the latter, which, after a time, again re-arrange themselves, and become histogenetic to form cells or tissues, which, in their turn, break down and become histolytic. We shall see, that not only development, but that growth and secretion, absorption and excretion, are only different names given to histogenetic and histolytic processes, and that these are brought about by formative and disintegrative molecules.

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* Montgomery on the formation of so-called cells. London. 8vo. 1867.

† See the author's note in the Trans. of the British Association. 1867.

No one can carefully watch the mode in which infusoria are developed, without being satisfied that they originate from the coalescence of molecules, and not from ova or spores, as has been imagined. On making a cold or hot infusion of any vegetable or animal substance, covering the vessel with a piece of paper, so as to exclude the dust, and then watching it every twelve hours, the first change visible to the eye is a slight opalescence, and the formation of a thin scum or pellicle that floats upon the surface. This appears at times, varying from a few hours to several days, according to the temperature of the atmosphere or the nature of the infusion. On examining the pellicle or film under high magnifying powers, it is seen to be composed of a mass of minute molecules, varying in size from the minutest visible point to that of one thirty-thousandth of an inch in diameter. These molecules are closely aggregated together, and must exist in incalculable numbers. (Pl. II. fig. 10, *a*.) They constitute the *primordial mucous layer* of Burdach, and the *proligerous pellicle* of Pouchet. The same pellicle, examined six hours later, shews the molecules to be somewhat enlarged, and these separated by the pressure of the upper glass are already seen here and there to be strongly adhering together in twos and fours, so as to form a little chain. Many twos, also, have apparently melted together, so as to form a short staff or filament—*bacterium.* (Pl. II. fig. 10, *b.*) Twelve hours after this, it may be seen that the grouping of the molecules in twos, threes, and fours, has become more general, and that several of these form new groups of eight lengthways. Many of them have melted together to produce longer bacteria. At the edges of the molecular mass, and in the fluid surrounding it, may now be seen a vibratile movement in the shorter bacteria, and a serpentine movement in the longer ones, whereby they are propelled forwards in the fluid—*vibrio.* (Pl. II. fig. 10, *c d.*) From the second or third to the fifth or seventh days, the vibrios are lengthened, evidently by apposition of groups of other molecules, to their ends. These unite together endways, to form a filament, which may extend a third or half, and in a few cases entirely across the field of the microscope. (Fig. 10, *e.*) After a time they may be seen motionless, evidently dead. This occurs at various periods. They now rapidly disintegrate, and thus a second molecular mass or pellicle is produced. In this, rounded masses may be seen to form, which strongly refract light not unlike pus corpuscles, or the colourless corpuscles of the blood. These soon begin to move with a jerking motion, dependent upon a vibratile cilium attached to one of their extremities—*Monas lens.* In a day or two other cilia are produced, the corpuscle enlarges, is nucleated, and swims through the fluid evenly. Varied forms may now occur in the molecular mass, dependent on the temperature, season of the year, exposure to sun-light, and nature of the infusion, all having independent movements. They have been denominated *Amœbæ*, *Paramecia*, *Vorticellæ*, *Kolpoda*, *Keronæ*, *Glaucoma*, *Trachelius*, *&c.* It is unnecessary to follow the development of all the forms that may arise. They originate always long after the primary vibrios are produced, in the secondary, tertiary, or even later molecular masses, resulting from the disintegration of previous forms. *

At other times, it happens that the molecular mass, instead of being transformed into animalcules, gives origin to minute fungi. In this case the molecules form small masses, which soon melt together to constitute a globular body, from which a process juts out on one side. These are *Torulæ*, which give off processes which are soon transformed into jointed tubes of various diameters, terminating in rows of sporules *(Penicillium)*, or capsules containing numerous globular seeds *(Aspergillus)*. Occasionally filaments are formed from the direct melting together of molecules, arranged longways *(Leptothrix)*. (See Pl. II. fig. 10, *f*). Why the molecules should sometimes arrange themselves in long rows, and at others into rounded masses, is probably dependent on varying degrees of limpidity and viscosity. But why both these forms of molecular matter should sometimes possess an inherent power of contractility, and at others not, it is impossible as yet even to surmise. But on the determination of this point, the variations existing between the different kinds of fermentation and putrefaction, are evidently dependent. In all these processes, varied forms, whether animal or vegetable, may be seen to arise in a clear fluid, from the coalescence of histogenetic and histolytic molecules, without ova or spores of pre-existing organisms.

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* See lecture on the Atmospheric Germ Theory and Origin of Infusoria, by the Author, *Monthly Journal of Medical Science*, March 1868.

The development of the *Ascaris mystax* offers another excellent example of the molecular law of organization. In describing it, I shall follow the observations of an independent accurate observer. The figures in Pl. VII., therefore, are copied from the original drawings of Dr Nelson, contained in his prize thesis, "On the Development of Entozoa," presented to the University of Edinburgh on his graduation, 1850. A portion of this thesis and some of the figures were subsequently published in the "Philosophical Transactions," vol. 142, for 1852. From the large number of drawings in the original memoir, it has been found necessary to make a selection, so that several of the intermediate changes have been omitted. A glance, however, at the series now given will, I trust, convey an accurate idea of what I understand by growth from successive histogenetic and histolytic molecules. Figs 1 to 3 represent the histogenetic changes which take place among the molecules deposited in the ovarian tube of the female worm, until the fully maturated ovum (Fig. 4) passes into the oviduct. Fig. 5 exhibits the contact with, and entrance of the spermatozoids into, the ovum. This act of impregnation is followed by breaking down or fusion together of the male and female elements (Fig. 6), and the formation of a chorion, the germinal vesicle being still visible

(Fig. 7). This also soon dissolves, and the interior of the ovum is now reduced to a mass of histolytic molecules, dense in the centre, but beginning to clear up at the circumference (Fig. 8). These now clear up still further, then meet together, concentrate themselves, and form histogenetic molecules, as seen in Figs. 9, 10, and 11 ; and a membrane forming round them (Fig. 11), another included cell is developed, as in Fig. 12). This divides itself into two (Figs. 13, 14). Each half separates into other two, as in Fig. 15, and the process of division is seen going on in Figs. 16, 17, 18, 19, and 20, until another histolytic mass of molecules is produced, as in Fig. 21. From this mass the perfect worm is formed directly by simple coalescence of the molecules, which again become histogenetic. They unite together, concentrate themselves, and separate from the vitelline membrane, Fig. 22. A cup-shaped depression then occurs (Fig. 23), which, passing through the mass, forms a ring (Fig. 24) that is seen to be divided at one place. The two ends of the ring now elongate and cross one another (Fig. 25), and the molecules go on coalescing to form the body of the worm. This next becomes spiral, as in Figs. 26 and 27, and on the breaking of the vitelline wall is extruded as the perfect animal (Fig. 28). During this process the molecules of the ovary first coalesce to form the ovum. After fecundation, the spermatozoids and germinal vesicle disintegrate and form histolytic molecules. The mass then re-arranges itself to produce an included cell, which, constantly dividing, is once more reduced to histolytic molecules. These by a third act of histogenetic coalescence produce the perfect animal.

In this and a vast number of similar observations, which will be subsequently referred to, it must be evident that a certain series of molecular transformations is necessary for the one which follows it. Thereby is produced a continual elaboration of matter—a constant chemical and morphological series of changes, the exact number and order of which in the production of organic forms only require time and perseverance to discover. Doubtless various conditions, dynamical, chemical, and vital, must co-operate in producing the result, and they must all influence molecular as well as every other kind of combination. Such considerations and facts must convince us of the error of endeavouring to place the source of special vital action in any particular form or arrangement of organic matter, whether fibre, cell, nucleus, or molecule. Each and all of these elements have their vital endowments, which re-operate on the others ; but inasmuch as the molecular element is the first as well as the last form which organised matter assumes, it must constitute the principal foundation of organisation itself.

THE CELL ELEMENTS OF THE TISSUES.

Definition.—By a cell is understood a microscopical object composed of an external envelope—the *cell wall* or membrane—containing an included body, which is called its *nucleus*, and having between the nucleus and cell wall a substance named the *protoplasm*, *cell sap*, or *cell contents.* These three constituents of the cell present great variation as to thickness, size, or bulk.*

Physical and chemical properties of cells.—The cell wall is more or less thick and resistant. In plants it is frequently double, the inner one having been denominated the *primordial utricle* by Von Mohl. Occasionally it is not separable from the protoplasm, nor can it always be shewn to exist as a distinct membrane. The nucleus is usually round or oval, is solid or hollow, homogeneous or molecular. It varies in size, and generally contains one or two included granules, called *nucleoli.* The contents may be fluid, gelatinous, or solid, and present the molecular, granular, fibrous, or crystalline forms.

These constituents of the cell are also for the most part of different chemical composition. The cell wall in animals is generally albuminous, and is partially soluble in acetic acid. In the inactive epidermic and cartilaginous cells, this change does not occur, as the cell walls in them are gradually converted into horn and chondrin. When actively performing their functions, the walls readily admit of endosmotic currents, swelling out on the addition of water, and collapsing when immersed in dense solutions. They may be rendered impervious from fatty or mineral degeneration, and thus lose their active properties. The nucleus is usually different in chemical composition from the cell wall, undergoing no change on the addition of acetic acid, and frequently becoming more dense, with a thickened outline, on the addition of that reagent. It seems to be more allied to the fatty than to the albuminous compounds. It exhibits a marked tendency to combine with pigments, a circumstance which has recently been taken advantage of in displaying the textures, by steeping them in a solution of carmine. The contents vary greatly in chemical composition in different cells. They may consist of the secretions formed in the numerous glands—may be watery, holding various substances in solution; oily or fatty; pigmentary, the various pigments being generally coloured fats, although, when black, it may be caused sometimes by melanin, at others by pure carbon; albuminous and sclerogenous, as in the cells of many plants; and mineral, as in many cells of plants and animals.

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* In recent times, with a view of still retaining the cell, as the ultimate element of organisation, some have shewn that it may exist without an external wall (Max Schultze), and others demonstrate that a nucleus is not necessary (Brücke). But it must be evident that without these parts we have only to do with a molecular mass, and that the adoption of such notions is equivalent to an abandonment of the cell theory. If an elementary part has not the structure of a cell, as defined by the founders and supporters of the cell doctrine, it can only create confusion in histology to apply the expression erroneously.

Cells may vary greatly with regard to their size, form, and relation to each other. In size some of them are as small as the 3000th, and others as large as the 400th, of an inch in diameter. In form they may be round, oval, polygonal, cylindrical, caudate, fusiform, branched, stellate, &c., &c. They may be densely crowded together, or widely scattered, isolated or aggregated, united by connecting fibres or tubes, or separated by various kinds of substance, called *intercellular substance.*

Varieties of cells.—Cells may be divided into three classes:—1st. Normal isolated cells, which never proceed beyond the cell form. These are lymph and chyle corpuscules, blood, nerve or ganglionic, fat, pigment, and glandular, secreting cells. 2d. Cells of transition—that is, cells which, for different periods in their earlier stage of development, present all the characters and functions of cells, but the tendency of which is to be transformed, or so arranged as ultimately to constitute a tissue. Among these must be placed many embryonic cells and fibre, epithelial and cartilage cells. 3rd. Cells only found in morbid conditions of the tissues, such as plastic or pyoid, pus, granule, cancer and tubercle corpuscles. Many of those classified among cells are in truth only nuclei, such as the chyle and blood corpuscles of mammals, tubercle corpuscles, and the free nuclei found in certain cancroid growths, especially fibro-nucleated tumours. To avoid unnecessary divisions, I have thought it advisable at present not to treat specially of a nuclear element of the tissues.

The origin of cells.—Passing over the views of the older observers, including those of Wolff, Von Baer, Raspail, and others, in which there is much that invites attention, the chief theories advanced on this subject may be limited to five.

1. *The theory of Schleiden and Schwann* (1839).—In a cytoblastema or amorphous substance, found either contained within cells already existing, or else between them in the form of intercellular substance, round corpuscles make their appearance, which are at first structureless or minutely granular. These enlarge and constitute the nuclei, around which a cell wall is formed by molecular deposition, and gradually expands by the progressive reception of new molecules between the existing ones. The interspace between the cell membrane and the cell nucleus is at the same time filled with fluid, and thus a nucleated cell is produced. Cells so formed may remain isolated, or, by subsequent development and coalescence of their walls in different ways, produce all the various textures.* Thus all tissues are derived from cells, and " the cause of nutrition and growth resides, not in the organism as a whole, but in the separate elementary parts—*the cells.*" †

2. *The theory of Goodsir* (1845).—It is not so much the cells as *the nuclei of the textures* which are the potential elementary parts of the organism, and which therefore may be called *centres of nutrition* or *centres of germination.* "As the entire organism is formed at first, not by simultaneous formation of its parts, but by the successive development of these from one centre" (the germinal spot of the ovum), " so the various parts arise each from its own centre, this being the original source of all the centres with which the part is ultimately supplied. From this it follows, not only that the entire organism, as has been stated by the authors of the cellular theory, consists of simple or developed cells, each having a peculiar independent vitality, but that there is in addition a division of the whole into departments, each containing a certain number of simple or developed cells, all of which hold certain relations to one central or capital cell, around which they are grouped. It would appear

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* Schwann and Schleiden's Researches, translated by the Sydenham Society, p. 172 *et seq.*

† *Idem*, p. 192.

that from this central cell all the other cells of its department derive their origin. It is the mother of all those within its own territory."*

3. *The theory of Huxley* (1853).—A homogeneous plasma first exists, in which spaces (*vacuoles*) are formed, and these contain the cell wall, contents, and nucleus. The walls of these spaces are called *periplast*, the nucleus *endoplast*. This last he considers comparatively an unimportant element. "The periplast, on the other hand, which has hitherto passed under the names of cell wall, contents, and intercellular substance, is the subject of all the most important metamorphic processes, whether morphological or chemical, in the animal and in the plant. By its differentiation every variety of tissue is produced; and this differentiation is the result, not of any metabolic action of the endoplast, which has frequently disappeared before the metamorphosis begins, but of intimate molecular changes in its substance, which take place under the guidance of the 'vis essentialis,' or, to use a strictly positive phrase, occur in a definite order, we know not why."†

While each of these theories has numerous facts in its support, no one of them is capable of embracing all the facts of organisation. Thus there are several tissues which have never been known to contain, or to originate from, cells, such as the sarcolemma, vitelline membrane, anterior and posterior layers of the cornea, and capsule of the crystalline lens. The blood corpuscles of mammals are not cells, but nuclei. The striated muscular fibre has been shewn by the researches of Savory, Lockhart Clarke, and Braidwood to be formed from the molecular mass outside the embryonic nuclei, while the mineral matter of bone is first deposited in the intercellular substance, outside and often at a distance from the cartilage cells. These facts are opposed to an exclusive cell theory, as they are also to a nuclear or germinal centre theory. It is true the originator of this last doctrine was obliged by them to extend the influence of his centre, externally over a certain distance or territory, whereby he hoped to embrace the actions which are carried on in the intercellular substance. But, as pointed out by the supporter of the third theory, the centre often disappears while development in the matter outside it is active. A study of the development of the skeleton proves that mineral matter is first deposited outside cells and their nuclei, and proceeds, not from, but towards them ; while the earthy matter often assumes forms that no known combination of cells can be supposed to produce. On the other hand, there can be no doubt that in many cases development does proceed from the centre, by proliferation both of the nucleus and of the cell ; so that the difficulties imposed upon us by each of these theories simply depend upon their exclusive character.

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* Goodsir's Anatomical and Pathological Observations, pp. 1 and 2.

† Brit. and For. Med.-Chir. Review, vol. xii. p. 306.

4. *The theory of the Author* (1855).—It was at the meeting of the British Association in Edinburgh (1850) that I pointed out to the Physiological sub-section the defects of the cell theory, as explanatory of the formation of various textures. In 1852 I read another paper on this subject to the Physiological Society of Edinburgh.* But it was at the Glasgow meeting of the British Association in 1855 I brought forward the molecular theory of organisation,† which may be shortly stated as follows:—The ultimate parts of the organisation are not cells nor nuclei, but the minute molecules from which these are formed. They possess independent physical and vital properties, which enable them to unite and arrange themselves so as to produce higher forms. Among these are nuclei, cells, fibres, and membranes, all of which may be produced directly from molecules. The development and growth of organic tissues is owing to the successive formation of histogenetic and histolytic molecules. The breaking down or solution of one substance is often the necessary step to the formation of another ; so that the histolytic or disintegrative molecules of one period become the histogenetic or formative molecules of another.‡

This theory unites the views of Schwann, Goodsir, and Huxley, and explains the otherwise irreconcilable ideas concerning development sometimes proceeding from the nucleus, at others from the cell, and at others from the intercellular substance. It is supported by all that is known of development, and more especially by the former accurate observations of Schwann, as well as by the recent researches of Rainey, Savory, Clarke, and Beale. The last physiologist, however, in addition to the facts he has described, has advanced the following theory :—

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* Edinburgh Monthly Journal, May 1852, p. 476.

† Report of the British Association for the Advancement of Science, 1855, p. 119.

‡ Proceedings of the Royal Society of Edinburgh, April 1. 1861.

The theory of Beale (1861).—Every living elementary part (a cell) is composed of matter in two states, one, living, active, formative ; the other, lifeless, passive, formed. The first he calls germinal matter, which corresponds generally to the nuclei of the tissues, but also to the entire colourless blood and pus cell. It alone selects pabulum, and has the power of re-arranging its elements so that the various materials characteristic of the different tissues, including cell wall, intercellular substance, and the secretions are formed. By its division and subdivision, the multiplication of cells is effected, nutrient matter or pabulum enters from without, permeates the formed material, and flows towards the germinal matter as to a centre. There it is animated by the existing living matter. The origin of new centres of living matter is always within pre-existing centres. Matters that have once lived pass outwards to constitute formed or inanimate substances, so that what was first formed is that which is most external, and at the greatest distance from the germinal matter.*

It will not be denied that in the living body organic matter, which enters it as food, was once alive, and when converted into what Dr Beale calls pabulum, and deposited in the body, is again capable of living, although in a different structural and chemical form. It must also be admitted that some organic parts may be more active than others, and portions of them are constantly dying and disappearing to give place to new ones. This constitutes what I have called histogenetic and histolytic changes. We can agree with Dr Beale, therefore, in considering generally that some parts in the organism are alive, whilst others are dying or dead. The action of his germinal matter and germinal centres differ little from what was described by Goodsir. But when it is maintained more specifically that the living parts are the germinal centres only, and that all the textures outside and between them are lifeless, that is dead, such a view is irreconcilable to what appears to be the most obvious physiological facts. According to this theory, for example, the intercellular matter of cartilage, the striated substance of muscle, and the greater portion of nerve are passive and lifeless, yet in the first occur those active changes whereby cartilage is transformed into bone ; in the second, those active contractions which produce motion; and in the third, that active sensibility which generates and transmits an influence when excited by various stimuli. All these, we maintain, are essentially vital actions, which can never appropriately be referred to dead substance.

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* On the Structure of the Simple Tissues, 8vo. London. 1861. See also "On Protoplasm," 12mo. London. 1870.

The recent modification of the molecular theory by Huxley, who supposes that all protoplasms are the same, and capable of being converted, as such, into one another, is opposed to observation. What we have pointed out, and shall subsequently further demonstrate is, that nutrition is dependent upon a series of histogenetic and histolytic changes of the protoplasm or molecular basis, without which development and function cannot be performed.

Reproduction of cells.—Cells once formed may propagate themselves in four ways:—(1.) *Endogenously*—cell may arise within cell; (2.) *Exogenously*—the included contents, molecular or nuclear, may be extruded from the cell, and form cells outside it; (3.) *Fissiparously*—the cell itself may divide, and separate to produce new cells; and (4.) *Gemmiferously*—a bud or small process may be given off from the cell wall, which may separate and be developed into a new cell. All these modes of cell reproduction may often be seen proceeding together in one plant; but in animals the first two are the most common in the adult, and the third in the embryo. In either case, the transformations may be traced to the active properties of their molecular constituents. Inside a cell, molecules may be precipitated, as well as outside, and there become obedient to physical and vital conditions, whereby they sometimes produce crystals and inorganic masses, at others nuclei, included cells, and other organic products.

Functions of cells.—Various cells possess different vital endowments. Whilst some, like the blood corpuscles, remain isolated, and assist in elaborating the fluid in which they remain, others are gradually transformed into the different tissues of the body, in order to give it support, ductility, and firmness. A third kind are busily occupied in secreting fluids, emptying them into reservoirs, and conducting matters which would be injurious out of the economy. Thus they are the organs of secretion and excretion. A fourth class either store up pigment, which gives colour to the textures, or accumulate pure oil or wax for important chemical or other purposes. A fifth class are endowed with contractility. So long as all these cell processes go on harmoniously, health is preserved. But sometimes a diseased condition is set up by an excess or diminution of one kind or another. The blood cells may be too many or too few. Glandular, epithelial, fibrous, cartilaginous or osseous growths may form from their local increase. Unusual colorations may be given to the textures, or obesity occasioned, by multiplication of pigment cells in the one case, and adipose cells in the other. Not unfrequently a material is poured out from the blood in a fluid state, which coagulates in a molecular mass, and then a new set of cells, such as pus cells, spring up in it, which break it down once again into a pulpy or diffluent mass, and at length by their own disintegration, allow the whole to be absorbed. Or, as in the case of cancer cells, these new formations, by possessing independent power of development, give origin to uncontrollable local and general growths of a fatal character.

These various endowments constitute the peculiar vital properties of cells, and prove that each must possess powers of attraction and selection. By attraction it draws from the neighbouring blastema the material necessary for its own growth and sustenance, which it converts, by a subtle chemistry of its own, into a variety of products. By selection, one cell appropriates this matter, and another that—often rejecting the substance that is greedily seized upon by its neighbour. In the higher animals, the nutritive blood appears to be the same in different organs ; and yet we see cells, apparently similar in structure and chemical composition, forming from that blood a viscous saliva, an acid gastric, or an alkaline pancreatic juice. They also possess physical properties which are essential to the vital ones, among which must be classed the power of endosmose and exosmose, and the chemical differences previously pointed out to exist between nucleus, contents, and cell wall.

Cell movements.—In the same way that molecules have movements peculiar to themselves, so in certain cases have the other constituents of the cell, such as the nucleus, protoplasm, and cell wall. The embryonic heart of the chick may often be seen to be composed of cells, each of which, by its contractile movements, appears to give the organ its power of propulsion. Infusorial animalcules, consisting of nucleated cells, slowly or quickly dilate and contract their cell walls. The fibre cells scattered through the adult tissues do the same. In the stalks of *Vorti-*

cellæ is a spiral filament, formed from the nucleus, having contractile power, as have the filaments of spermatozoids, developed within cells. The walls of cells, again, have frequently hair-like processes attached to them externally, which are in constant movement, and are termed "cilia."

Conditions necessary for cell life.—The development of cells is dependent on certain conditions, which, so far as we are acquainted with them, appear to be as follows :—(1.) They must bear a certain relation to a nutritive fluid or *blastema*, from which they can attract and select the various substances necessary to enable them to carry on their respective functions. The most active growing cells are those that swim in such a fluid. In the higher plants and animals, the nutritive fluid (sap or blood) is distributed throughout the economy in a series of canals. (2.) A certain temperature is necessary to cell life, as it will not continue below zero or above 145° Fahr. As a general rule, a low temperature checks, while an elevated one is favourable to cell growth. (3.) Room for expansion is necessary to perfect cell formation. They grow most rapidly, and are best formed in fluids or very moist substances. When they begin to press upon one another, or upon unyielding tissues, their development is checked or destroyed. (4.) An appropriate locality has evidently a great influence over cell formation, and this independent of mere temperature and the other circumstances referred to. This is well observed, not only in nature generally, but in the reproduction of tissues in man ; the new matter originating the cells being in most cases the same, but more or less governed, in respect of the ultimate development, by the neighbouring structures. Lastly : The physical condition of the cell itself governs its development. If the cell wall becomes infiltrated with mineral matter, liquids do not readily pass through it ; if the cell fluid becomes loaded with albuminous, fatty, or mineral substances, or if the nucleus disappear, the growth and function of the cell are destroyed. The conjoined integrity of cell wall, contents, and nucleus, seems to be necessary for cell life, as each of these operates on the others, and on the surrounding blastema by endosmose and exosmose. Cells, therefore, are not absolutely the simple elementary parts which some consider them to be, but complex structures, in which at least three distinct substances enter to make the whole. Compared with molecules, they are a higher stage of existence, and essentially connected with the most important vital processes of the economy, such as nutrition, secretion, and reproduction. Conjoined with other elements of the textures, they are also essential to locomotion, sensation, and mental acts. Each individual cell, like every molecule, is endowed with a distinct life of its own, but of a more complex character. It is born, grows, arrives at maturity, declines, and dies. Many cells may even reproduce their own species, while others, by further development, are transformed into still higher forms of tissue. Hence our notions of life in general, as seen in the compound organism of a tree or a man, must always have reference to the multitude of minute molecules and cells, the united lives of which make up its own.

Perhaps nothing has more tended to revolutionise medical practice in recent times than the establishment of the cell theory. We observe that most of the great functions of the economy are carried on through the agency of cells, and that even pathological states are entirely owing to their existence, development, and degeneration. Thus pus—that fluid which surgeons formerly considered as a deposit or secretion foreign to the frame, irritating in its nature, and which therefore ought to be let out of the body as soon as possible—is, like the blood, a bland living fluid, crowded with multitudes of compound animal existences, which are born, live, and die as man himself does. That dreaded disease, cancer, owes its so called malignancy solely to the power of endogenous reproduction possessed by its cells ; while all alterations of texture, of nutrition, of secretion, and of development are, in truth, connected with their history. The conditions or laws which regulate cell life therefore become of immediate practical importance to the physician and surgeon. Thus the growth of cells is influenced by the same circumstances as influence growth in general. Cold and heat have long been recognised as the most powerful means of checking or hurrying forward the evolution of young plants and animals. This is the explanation of the effects of these agents on the products of inflammation. Does the surgeon wish to prevent suppuration—he applies cold lotions or ice ; if he wishes to favour it, he applies warm poultices. In the same manner as the horticulturist, when he desires to force fruit, places the plant in a hothouse, and supplies water,—so does the surgeon surround his indurated abscess with a local hotbed of heat and moisture. So likewise, the influence of compresses and pressure in restraining or retarding growth finds its explanation in the necessity all rapidly growing parts experience for room to expand in. We have previously seen that, inasmuch as cells are dependent on the existence of a molecular blastema, so the composition of this, as influenced by food and drugs, must point to a modification of cell function. But, above all, the vitality of these minute structural elements being inherent in themselves, must convince medical men that the morbid changes which they originate are extra-vascular, and thus induce them to look beyond that former common explanation of disease—namely, the so-called "action of the vessels"—for an explanation of pathological phenomena. Hence the conviction of the inutility of bloodletting and other remedies, which used to be so popular.

The varieties of cells have been previously referred to, we have now to describe the special characters and functions of each.

Chyle and Lymph Corpuscles.—*Chyle* differs from lymph in possessing a molecular basis, discovered by Gulliver, consisting of minute particles, varying in size from a point barely visible to the 1·20,000th of an inch in diameter. They are the result of the primary digestion, and are composed of oil surrounded by a layer of albumin. They strongly refract light, and are soluble in an excess of ether. Floating amongst these we observe granular and globular bodies about the 1·4000th of an inch in diameter, which, on the addition of acetic acid, exhibit a thicker margin than they did before. In chyle taken from the thoracic duct there are also bi-concave flattened disks, exactly resembling the coloured blood corpuscles in size and form, but destitute of colour. Between these two kinds of corpuscles all kinds of intermediate changes may be observed, so that there can be little doubt that the former become flattened, and are changed into the latter. They are in fact embryo blood corpuscles, which become coloured in the lungs. (See Sanguification).

Lymph is a transparent fluid, which contains a few molecules and cells, the latter varying in size from the 2000th to the 1000th of an inch in diameter. They are globular in shape, of molecular aspect, having a distinct cell wall and nucleus. On the addition of water they are enlarged by endosmose, while acetic acid dissolves the cell wall, and exhibits the nucleus as a single, double, or tripartite granular body. Occasionally it is oval, elongated, bent, and crescentic. These bodies are identical with the colourless cells of the blood, and may be seen in that fluid and in the chyle, mingled in varying numbers with other corpuscles and molecules (See Pl. III. figs. 1, 2, and 14).

Blood Corpuscles.—Three kinds of corpuscles exist in the blood—1st, a few molecules, which are those of the chyle, and are generally increased in number during active digestion. 2d, colourless cells, which are identical with those of lymph just noticed; and 3d, coloured corpuscles, which are the essential elements of the sanguigenous fluid. These last require special notice here.

Shape.—In man and mammals generally, the form of the coloured blood corpuscles is that of a bi-concave circular disk (Pl. III. fig. 3). Examined by transmitted light, the circular margin and shadowed spot in the centre is dark or light according to the focal point in which it is viewed. Seen edgeways, it presents either a straight line or a slight double concavity on each side. They have a great tendency to turn on their side and form rouleaux (Pl. III. fig. 3 and 13). Their shape undergoes rapid alteration on the occurrence of evaporation, when the blood is exposed to the air, the margins becoming irregular, crenated, serrated, or beaded (Pl. III. fig. 4). The same occurs after the addition of various re-agents as will be seen further on. In the *Camelidæ*, as was first shewn by Mandl, the corpuscles are oval, not flattened, and, like the bi-concave circular disks, contain no included body. In birds, reptiles, and fish, the corpuscles are oval (Pl. III. fig. 6, *a*, *b*, *c*, *e*, *f*). The oval varying in the bird, salamander, and frog. These corpuscles are distinctly nucleated, and are, therefore, cells. In the invertebrata, the shape varies much, being globular, oval, or fusiform (Pl. III. fig. 6, *h*). They may be also cellular, nuclear, or molecular.

When examined by a good oblique direct light on a black ground, Dr J. W. Freer of Chicago, shewed me that the coloured blood corpuscles of man and of the frog exhibited a prominence in the centre, as shewn (Plate III. fig. 12).*

Colour.—The colour of the blood corpuscles, as seen under the microscope, is that of a straw yellow. It is only when aggregated together in mass that the colour looks red, in the same way that the concentrated yellow pigment of saffron does when seen by transmitted light.

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* Chicago Medical Journal, April 15. 1869.

Size.—The size of these bodies varies greatly in different animals. The most careful and elaborate researches on this subject has been made by Mr Gulliver, who, with the animals of the London Zoological Gardens at his disposal, measured the blood corpuscles of one hundred and seventy-six different mammiferous animals, and of two hundred and four different species of birds.* The following measurements, in fractions of an inch, will give an idea of the extreme variations which exist :—

	Breadth.	Thickness.
Man	1.3200	1.12.400
Do. Fœtal . . .	1.2800	
Elephant . . .	1.2745	
Musk Deer . . .	1.6330	
	Long Diameter.	**Short Diameter.**
Camel	1.3250	1.5921
Ostrich	1.1649	1.3000
Pigeon	1.2314	1.3429
Humming Bird . . .	1.2666	1.4000
Frog	1.1108	1.1821
Crocodile . . .	1.1231	1.2286
Proteus	1.400	1.727
Pike	1.2000	1.3555
Shark	1.1143	1.1684
Earth-worm . . .	1.110	1.1200
Leech (after addition of water) .	1.3000	1.3600

The size of the coloured corpuscle bears a relation to the calibre of the ultimate capillary vessels, which are just large enough to admit of one passing in single file. Injections, therefore, of the blood vessels are more easily made in reptiles than in any other animals.

Chemical Constitution.—Hoppe-Seyler † has shewn that the blood corpuscles consist mainly of hæmoglobin, with traces of albumin, cholestrin, protagon, phosphate of potash, but no fats.

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* Appendix to his Translation of Gerber's General Anatomy, 1842.

† Hoppe Seyler, Chemische Analyse. 1870.

Effects of Reagents.—The addition of water causes these bodies to lose their colour, to swell out and become globular. Syrup, gum, albumin, and dense saline solutions, renders them flaccid, mis-shapen, irregular in outline, contracted, puckered, &c., as represented (Plate III. fig. 4). Acetic acid appears at first wholly to dissolve the mammiferous corpuscles, but their form may be faintly recognised on adding to them tincture of iodine. But on the oval corpuscles of birds, reptiles, and fish, the effect is simply to dissolve, or render very transparent, the cell wall, whilst the nucleus is unaffected, and rendered more clearly visible in the field of the microscope. (See Plate III. fig. 6, *d*). Astringent solutions, and especially a solution of crystallised nitrate of silver, causes puckerings and folds to appear in the cell wall. This is well seen in the corpuscles of the newt, and were supposed by Martin Barry to indicate the existence of a spiral filament. A solution of Magenta (the chloride of rosaniline), causes a minute molecule to appear on the external margin, as pointed out by Dr Roberts of Manchester. This I ascertained by using very high powers (1.25th of an inch focus) to depend upon minute rhomboid crystals adhering externally to the edge (Plate III. fig. 7, *a*, *b*). The same observer, also, was the first to describe the effect of a dilute solution of tannic acid (2 grains to the ʒi of distilled water), when added to the coloured blood corpuscle, causing one, and sometimes two, protrusions to take place at its circumference (Plate III. fig. 8). If, in addition to the tannic acid, tincture of iodine be added, I have seen this protusion, or an included portion of it, strongly coloured, and present the various forms represented in fig. 9.

Effects of Disease.—When the blood becomes inspissated, as in acute inflammation, the coloured corpuscle loses its rounded outline and elasticity, becomes flask shape, and instead of rouleaux, forms irregular masses, as in Plate III. fig. 5, or becomes oval, dragged out and elongated by adhering molecular fibres of fibrin (Plate IV. fig. 2). On one occasion I saw, in a case of cholera which was under the care of Dr Cowan, the remarkable appearance, figured Plate III. fig. 10. In hæmatocele, or in the act of disintegrating, the corpuscles may become fatty, and exhibit in their interior bright refracting molecules (Fig. 11). In the spleen pulp, and in apoplectic extravasations, groups of them may not unfrequently be seen to be surrounded by a hyaline substance, probably squeezed from their substances, as in Plate III. figs. 20 and 21. Leucocythemia consists of an increase of the colourless and diminution of the coloured corpuscles, as represented, Plate III. figs. 13 and 14. This morbid condition will be referred to at length in speaking of the blood glands. (See Sanguification).

Origin and Development.—The blood corpuscles in the embryo are formed in the interior of the cells of the vascular layer of the germinal membrane. In the adult, they are produced in the interior of the lymphatic or blood glands, as will be more fully detailed under the head of Sanguification.

Structure.—The opinions on this point which have been put forth are far too numerous even to be enumerated. We can only refer to the principle ones. The coloured blood corpuscle has been regarded, 1. as an animalcule (Kircher, Borelli); 2. as a globule of oil (Malpighi); 3. as consisting of six particles, each of which were formed of six smaller ones (Lewanhoeck). This was the basis of the celebrated theory of *error loci* put forth by Boerhaave; 4. as a ring with an opening in the centre (De la Torre); 5. as a vesicle containing a loose moveable nucleus (Hewson); 6. as a fibrinous solid body of a bi-concave form (Young, Hodgkin, Lister, Gulliver); 7. as a vesicle containing a nucleus surrounded by air (Schulz); 8. as a vesicle containing a semifluid colouring matter (Donné); 9. as an organised cell, containing six nuclei; 10. as a body containing a spiral filament, the elementary basis of all the tissues (Martin Barry); 11. as a vesicle, containing a nucleus attached to it by its poles, surrounded by a coloured liquid (Rees and Lane); 12. as a vesicle having a double envelope (Roberts, Hensen); 13. as a homogeneous body in the living animal, which is partly coagulated on leaving the body, its centre more especially becoming solid (De Blainville, Mandl, Savory).

Of all these opinions, I consider the last to approach nearest the truth, and that the mammiferous corpuscle, when circulating in a living animal, consists of a membrane and some solid contents. Indeed, on more than one occasion, I have succeeded, when perfectly fresh, in lacerating that membrane, and seeing the fluid contents flow out. Puckered folds may also occasionally be seen in it, especially in the corpuscles of the newt after the addition of coagulating agents. But subsequently the fluid contents coagulate, which, as De Blainville thought, are probably more dense in the centre, as in the case of the crystalline lens, and of the contents of the nerve tube. This view agrees with the great elasticity seen to exist in the corpuscle when alive—its possession of endosmose and exosmose—the influence of reagents—the central prominence demonstrated by Professor Freer of Chicago, and the escape of a glutinous matter, capable of being partly tinged by pigments, after the addition of tannic acid.

Functions.—The chief use of the yellow blood corpuscles is, by their solution, to form the liquid plasma of the blood (*liquor sanguinis*), and fit it for the important function of nutrition. At the same time, they serve, by the chemical changes they undergo in the lungs and in the capillaries, to diffuse oxygen throughout the economy, to promote thereby varied transformations between the solids and fluids, and to keep up animal heat. They further act mechanically in keeping the capillaries patent.

NERVE CELLS.—In the nervous grey matter of the brain, spinal cord and ganglia, are embedded cells, which vary greatly in shape, size, and structure.

Shape.—They may be globular or oval, as in the Gasserian and other ganglia (Plate III. fig. 28, *a*, *b*, *c*). Two processes may project from them at opposite sides, continuations of the nerve tubes, as in the ganglia on the posterior roots of the spinal nerves. They are then called *bi-polar* (Fig. 28, *d*). There may be more of them, varying from three to seven, when they are called *multi-polar*, as in the grey matter of the spinal cord (Fig. 28, *e*, *g*). They may be pear-shaped, the pointed extremity prolonged and dividing into numerous branches, as in the grey matter of the cerebellum (Fig. 28, *f*). Lastly, Dr Beale has described a peculiar form and arrangement in certain ganglionic nerve cells of the frog, pyriform in shape, having a straight and a spiral filament (Fig. 28, *h*). These have also been described by Arnold and Courvoisier.

Size.—These cells vary greatly in size, the smaller in the cerebellum being about 1.2500th of an inch in diameter, and the larger in the Gasserian ganglion often reaching the size of 1.400th of an inch.

Structure.—These cells have a distinct but delicate cell wall, outside which is occasionally seen a layer of nucleated areolar tissue. The nucleus is distinct, with one or more nucleoli, and varies as much in size as the cell does. The contents consist of fine molecules, generally colourless, but occasionally light or dark brown, which communicate to certain ganglia, such as the *corpus niger*, a brownish tint. The processes coming from the bi-polar or multi-polar cells must be regarded as continuations of the nerve tubes, whereby connections are maintained with one another, or with different portions of the cerebro-spinal or sympathetic centres. The addition of water causes them to swell out and enlarge, while acetic acid partially dissolves them.

Functions.—These cells are supposed to be connected with the evolution of nerve force. They are not the only nervous structures possessing this power, as the molecular and tubular nerve elements are similarly endowed. They also subserve the purpose of conveying, modifying, and diffusing the influence of impressions. These properties, however, are so essentially concerned with other functions of the nervous system, that they will be more fully considered when speaking of the nerve tubes. (See Tubular Elements of the Tissues.)

FAT CELLS.—The solid fat of the dead body is fluid during life, and contained within distinct cells, with delicate walls, named fat or adipose cells. When isolated, they are globular or oval in shape, but when aggregated together are polygonal, from being pressed together (See Plate III. fig. 26). They strongly refract light. The young cells vary greatly in size. They may be as small as the 1.3000th of an inch in diameter, as may be seen in the mesentery of a lean animal, or the 1.500th of an inch, as in ordinary adipose tissue. In fatty tumours they may become as large as 1.300th of an inch. On adding water to the young cell, it often enters it by endosmose, and collects between the cell wall and the oil in the interior. In this wall a nucleus may frequently be seen imbedded, and outside it crystals of margarin, which may project from the surface like a bundle of needles, or ramify on its internal surface in an arborescent form. (See Plate I. fig. 15.) The cell walls are easily ruptured, when the oil masses float in loose globules in the field of the microscope. Ether causes the cell walls to collapse and the oil to dissolve. Liquor potassæ does the same thing, leaving a brownish viscous mass. These cells are readily seen developing in young animals in the mesentery and subcutaneous areolar tissue. Minute granules collect outside the blood vessels, which, aggregating in a mass, form the nucleus. Around this the cell wall is formed, and oil accumulates in the interior, first in the form of molecules, which melt into one another. (For Chemical Composition and Origin of Fat, see Fatty Proximate Principles, p. 18.)

Pigment Cells.—Variously coloured pigments are found in the interior of cells, in plants, and animals (see Pigmentary Proximate Principles, p. 30), but the term, pigment cell, is usually applied in man to that kind of cell formation which contains in its interior brown or black molecules. These are found in the choroid membrane, the lungs, and in the skin. In shape they may be globular and oval, as in the lung ; hexagonal, fusiform, or branched in various parts of the choroid, and polygonal in the epidermic cells of the dark races, and in the areola of the nipple. (Plate III. fig. 27.) The tint may vary from a faint yellow or brown to the deepest black. The pigment is always molecular, situated between the nucleus and cell wall, often obscuring, but sometimes permitting the former to be seen clear and colourless. They vary in size, from the 1.1200th to the 1.500th of an inch in diameter. In the choroid and skin, the pigment disappears on the addition of chlorine or hydrochloric and nitric acids, but in the lungs it resists every reagent, including that of the blow-pipe. In the former case, it is a peculiar substance called melanin (see p. 31), in the latter it is pure carbon. Acetic acid often dissolves the cell wall, when the pigment molecules escape and are dispersed. These pigment cells give a special character to a certain morbid growth named melanosis. The peculiar vital properties of the pigment molecules within the cells have been previously referred to. (See pp. 39 and 40.)

Gland Cells.—The cells which constitute the essential secreting parts of glands are too numerous to be treated of separately, and will be referred to more particularly under the function of Secretion. They vary greatly in size, structure, chemical composition, and individual properties, but are alike in possessing general powers of attraction and selection, whereby they eliminate from the blood a variety of products necessary for secretion and excretion.

Transition Cells.—Under this head it is necessary to refer to a class of cells, which, during one period of their lives, possess all the characters and properties of cell formations, but at another, pass gradually into other more complex and permanent formations. To this class belong,—

1. *Embryonic Cells.*—In the embryo, and in the early development of healthy and morbid tissues, molecules, nuclei, and cells present themselves, which exhibit no distinctive marks, but which, in the progress of development, are transformed into various tissues. Of these, the variously shaped cells seen in a recent exudation on a serous membrane, and which are subsequently transformed into blood vessels, constitute a good example.

2. *Epithelial Cells.*—These may assume various forms, such as, 1. flat or tessellated, when they adhere by their edges ; 2. columnar, when they adhere by their sides ; 3. ciliated, having cilia on their free surfaces ; and, 4. globular, which is a form of gland cell. The large mass of cells constantly forming in the internal layer of the epidermis, as they pass outwards undergo chemical and vital changes. They are thereby converted into horny matter, and aggregate together, or split up, so as to arrange themselves into hair, nail, hoof, horn, feather, scale, and, in the lower animals, especially insects, endless varieties of forms adapted to many purposes. In the mucus, covering various mucous surfaces, round or oval cells are embedded, often called mucous corpuscles, which are only a form of epithelial cell (Plate III. fig. 16).

3. *Fibre Cells.*—These corpuscles are for the most part fusiform in shape, and though isolated in the skin, are more commonly aggregated together to form layers round tubes and hollow viscera, such as certain blood vessels and the alimentary canal. They also constitute the radiating and circular fibres of the iris. Some are, and others are not, possessed of contractility ; and what is further remarkable concerning them is that, in some tissues, they may be contractile at one period and not at another. Thus, in the unimpregnated uterus they exert no contractile action, but during pregnancy, or when otherwise hypertrophied, they enlarge and become contractile, so that at a given moment they are capable of expelling the fœtus or other included body. (Plate IV. figs. 5, 13.)

4. *Cartilage Cells.*—These bodies will be described subsequently. (See Cartilage and Bone.) In the embryonic osseous tissue they are essentially concerned in the transformation of

cartilage into bone; and although some of them are more permanent in man, it is observable that as age advances there is everywhere a tendency shewn for cartilage to pass into bony texture.

Morbid Cells.—Under the influence of irritation and other morbid causes, the cells previously described may increase in numbers endogenously or exogenously, and not unfrequently new cells are formed in matter exuded from the blood vessels. In either case, such cells may present modifications that require to be especially studied, forming as they do, essential parts of diseased processes and growths. The pathological cells are,—

1. *Pus Cells.*—Normal or good pus, when examined under a microscope, is found to consist of numerous corpuscles, floating in a clear fluid, the *liquor puris.* The corpuscles are globular in form, having a smooth margin, and finely granular surface. (Plate III. fig. 17.) They vary in size from the 1.2000th to the 1.1200th of an inch in diameter. There may be generally observed in some of them a round or oval nucleus, which is very distinct on the addition of water, when also the entire corpuscle becomes distended from endosmosis, and its granular surface is more or less diminished. On the addition of strong acetic acid, the cell wall is dissolved, and the nuclei liberated in the form of two, three, four, or rarely five granules, each having a central shadowed spot. If, however, the reagent be weak, the cell wall is only rendered very transparent and diaphanous, through which the divided nucleus is very visible (Plate III. fig. 18). Occasionally these bodies are seen surrounded by another fine membrane, as in Fig 19, and numerous diaphanous or hyaline bodies may be seen floating among them. The production of these has been previously explained. (See p. 44 and Plate II. fig. 11.) At other times they are not perfectly globular, presenting a more or less irregular margin, associated with numerous molecules and granules. This occurs in what is called scrofulus pus, and various kinds of unhealthy discharges from wounds and granulating surfaces. In gangrenous and ichorous sores, a few of these irregular pus corpuscles are associated, not only with a multitude of molecules and granules, but with transformed and broken-down blood globules, the *debris* of the involved tissues, &c., &c.

The exclusive cell pathologists maintain that pus cells originate within the nuclei of the fibrous tissues, or what they call connective tissue corpuscles. Ever since this statement was put forth, I have in vain sought among morbid products for any proof of its accuracy. My assistants and my annual practical classes of histology have made numerous observations and experiments, especially putting setons through the skin and cornea of living animals, and a few days afterwards examining the altered tissues, and have never seen pus corpuscles in the interior of these nuclei. German pathologists, firm believers in the views of Professor Virchow, have, for three months together, in my clinique, ransacked the inflamed and purulent tissues of the body, in the hope of finding and shewing me even one enlarged connective tissue corpuscle, containing pus cells, but have at length admitted that nothing of the kind could be found. I have requested all the pathologists of this city, and many of my foreign *confréres*, to shew me in recent specimens, or in prepared preparations, any one example of such an occurrence; but notwithstanding their belief that they had seen it, they have not ventured to demonstrate to me a fact, so simple in itself, and one of such consequence to the truth of the cell pathology they support. I do not believe, therefore, that pus cells originate in the interior of other cells. On the other hand, I am at all times prepared to demonstrate, both from recent specimens and from numerous preparations, that pus cells really originate in the molecular matter of exudations from the blood vessels,—a fact that may readily be seen in a specimen of acute pneumonia, and in other examples of recent purulent formation.

Another theory of the origin of pus cells, founded on an observation originally put forth by Addison (1843),* has recently been contended for by Cohnheim, viz., that they pass bodily through the vascular walls, being in fact colourless blood cells. Ever since Addison's views on this matter were published, this phenomenon, though carefully looked for by myself and assistants, has never been observed. (See Inflammation.)

2. *Granule Cells.*—It was shewn by Reinhardt, that all kinds of cell formation, under certain circumstances, undergo the fatty degeneration. The manner in which this is accomplished is in all cases the same. A few fatty molecules first form between

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* The Actual Process of Nutrition in the Living Structure demonstrated by the microscope, &c. By William Addison, F.L.S. London, 1843.

the nucleus and cell wall. These increase in number, and some of them apparently are fused together to produce larger ones. This process goes on until at length the whole contents of the cell consist of fatty molecules and granules. The nucleus is now no longer visible, and in many cases the formation of molecules takes place within the nucleus in the first instance. In either case, the cell wall, distended by the accumulation of fatty particles, at length gives way, and the included oil granules either separate, or for a time adhere together in granular masses. Sometimes these bodies are easily ruptured by external violence ; at others they are more resistant, and the oily matter is forced through the cell wall, and collects outside, whilst the cell itself is more or less collapsed. In this way collections of fatty granules and granule cells takes place in the ducts of all glands which are lined by epithelium ; in the air vesicles of the lung and in the bronchi ; in the cells of the liver, causing fatty degeneration of that organ ; in the shut sacs of vascular glands, as the spleen, and in all cell formations from exudation, especially those of pus and cancer. Their formation constitutes the special lesion of chronic inflammatory softening of the brain. (See Plate III. fig. 22.)

3. *Cancer Cells* may be round, oval, caudate, spindle-shaped, oblong, square, heart-shaped, or of various indescribable forms, produced by pressure on their sides. In size they vary from the 1.1200th to the 1.400th of an inch in diameter. The cell wall, when young, is smooth and distended ; when old, it is more or less corrugated and flaccid. Each cell contains at least one nucleus, often two or more. Most commonly there is only one. which is round, or more generally oval, and contains one or two granules or nucleoli. The included nuclei also vary in size, and may present all stages of transformation into cells. It is the unusual facility for endogenous cell growth that communicates to cancer its so-called "malignity." (See Plate III. fig. 23.) Between the nucleus and cell wall there is a colourless fluid, which, at first transparent, becomes afterwards opalescent, from the presence of molecules and granules. On the addition of water, the cell wall becomes distended by endosmose, and is enlarged. When acetic acid is added, the cell wall is rendered more transparent, and in young cells is entirely dissolved, whilst the nucleus, on the other hand, either remains unaffected, or its margin becomes thicker, and its substance more or less con-

tracted. These cells may originate either in an exudation, or from the proliferation of previously existing cells. It is only in the former case, however, or when they become infiltrated throughout the texture of an organ that cancer can be distinguished from glandular, epithelial, enchondromatous, or other morbid growths.

4. *Tubercle Corpuscles.*—A small portion of tubercular matter squeezed between glasses, and examined under the microscope, presents a number of irregular shaped bodies approaching a round, oval, or triangular form, varying in their longest diameter from the 1.2000th to the 1.1200th of an inch. These bodies contain from one to seven granules, are unaffected by water, but rendered very transparent by acetic acid (Plate III. fig. 25). They are always mingled with a multitude of molecules and granules, which are more numerous as the tubercle is more soft (Plate III. fig. 24). Occasionally, when softened tubercle resembles pus, constituting scrofulus purulent matter, we find the corpuscles more rounded, and approaching the character of pus cells. They do not always, however, on the addition of acetic acid, exhibit the peculiar granular nuclei of these bodies. The grey granulations described by Bayle, may be seen on careful management of the light, after the addition of acetic acid, to contain similar bodies to those described as tubercle corpuscles, closely aggregated together, with their edges indistinct, and containing few granules. Tubercle corpuscles originate in a chronic exudation of the lung, under circumstances where cell formations seldom if ever occur in it. They are abortive histogenetic nuclei, and not the result of a disintegrative process, as some have supposed. (See Tuberculosis.)

The careful study, and a knowledge of the characteristic differences existing between cells, is often one of great difficulty, but should be perseveringly followed as a means of obtaining results in diagnosis and treatment of the highest importance.

THE FIBROUS ELEMENTS OF THE TISSUES.

Definition.—By an elementary fibre is to be understood a solid microscopical filament, characterised optically, when round, by two broad external opaque lines, with a transparent line between them. They vary in thickness and chemical composition. Like the molecule and the cell, the fibre has been considered as the elementary basis of organisation (Haller).

The various kinds of fibre may be classified histologically into molecular, nuclear, and cell fibres, all of which may be non-contractile or contractile.

MOLECULAR FIBRES.—1. *Non-contractile molecule fibre* may be seen in mucin and in the clot of blood (Pl. IV. figs. 1 and 2) to be composed of rounded molecules, agglutinated together end to end. In a layer on the surface of rheumatic or inflammatory blood, molecular fibres may be seen to form under the microscope, as pointed out by Dr Addison, now of Brighton. In the clear fluid, a deposition of molecules occurs, which arrange themselves in rows, stretch across the field of the instrument, and at length render the whole opaque, and constitute the fibrinous coagulum of the clot. The same occurs in mucin.

2. *Contractile molecular fibre.*—We have previously seen (p. 46) that on the surface of an infusion, molecules arrange themselves in short rows, melt together, and assume a vibratile movement. As they grow longer, the motion becomes serpentine, and they dart or wriggle rapidly through the fluid. These are the so-called *vibriones* or *spirilla.* In this manner actively moving and contractile filaments form by apposition of molecules, without the agency of nuclei or cells. (Plate IV. fig. 11.) The addition of acetic acid generally causes partial solution of these fibres.

3. *Striated muscular tissue.*—The most important form of molecular contractile tissue, is the striated or voluntary muscular fibre. This in its turn is made up of numerous smaller fibrils or *fibrillæ*, and hence is called a *fasciculus.* Each muscular fibre or fasiculus is polygonal in shape, as is readily seen on making a transverse section of a group of them (Pl. IV. fig. 18). Their average diameter in man is about the 1.352d part of an inch, and in woman about 1.454th part. They are much broader in fishes, and much narrower in birds. They are surrounded by a delicate, structureless membrane, first demonstrated by Bowman, and called by him the *Sarcolemma.* It may be shewn by strongly irritating the living fasciculus, whereby its sarcous structure is ruptured, leaving the membrane entire (Fig. 22), or by adding to it water, when the membrane is raised by imbibition in the form of bullæ on the surface, as in the lower portion of Fig. 23.

The transverse striæ consists of alternate dark and light lines running across the fasciculus. These describe the curve presented to the eye, being generally rounded, but not unfrequently angular, if an angle of the polygonal outline of the fibre lie upwards. The striæ are finer, that is closer together, in fishes, and coarser or wider in the crustaceæ. In certain conditions of the fasciculus it readily breaks across in the direction of the striæ (Fig. 19); in others, lengthways in the direction of the fibrillæ (Fig. 20). When these last are isolated, it may be seen that each is made up of alternate light and dark particles of a square or oblong shape (Fig. 24). The structure of these was first shewn by Dr Dobie of Chester,* to consist, under high magnifying powers, of dark and light markings, occupying the entire breadth of the fibrillæ, the light one being again divided by a delicate dark line (Fig. 25). This remarkable appearance characterises the finest fibrillæ that has yet been arrived at by the most skilful manipulations that can be practised, as seen under a power of 2000 diameters linear. Acetic acid renders more transparent the whole substance of the fasciculus, and brings into view nuclei, varying in size and shape, embedded in its substance (Fig. 21).

If, immediately after killing an animal, a fasciculus be rapidly placed on a glass slide, and examined under a microscope, it may be seen, when irritated, to contract and shorten itself, by the striæ becoming thinner, flattening themselves against each other, and causing a corresponding thickening of the fasciculus, as in the lower portion of Fig. 23. Sometimes this takes place uniformly throughout the whole length of the fasciculus; at others, at one extremity, and occasionally here and there causing alternate swellings. Friction on the glass may produce these last effects. Formerly it was supposed that the fasciculus was shortened by a zig-zag movement. But this appearance is now recognised as a proof of extreme relaxation in muscle.

The structure of Muscle.—Various opinions have been held on this subject. The older histologists considered the striæ to be caused by puckerings or edges in the external sheath; but all recent observation with good achromatic microscopes demonstrate that they are caused by the regular apposition side by side of the dark and light particles of the ultimate fibrillæ. The cohesion of these is such that sometimes they separate cross-ways to the fasciculus, forming disks ; at others, long-ways, producing minute fibres. (See Pl. IV. figs. 19 and 20.)

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* "Annals and Magazine of Natural History." 1849.

Chemical composition of Muscle.—A quiescent muscle gives an alkaline reaction, but when the muscle is tetanised, the reaction becomes acid from the development of lactic acid. Helmholtz has found that, by tetanisation, the substances soluble in alcohol are increased, while those insoluble are diminished. The semi-fluid, contractile substance of muscle, when isolated from sarcolemma, divides, according to Kühne,* into a fluid portion, which he terms muscle-serum, and a solid coagulum, which he terms muscle-clot, or myosin. The muscle-serum contains three forms of albumin, one coagulating at 30°, a second coagulating at 45°, and a third at 75° C. Myosin has been already described in treating of the chemistry of the tissues. (See p. 10.) An analysis by Von Bibra shews that 100 parts of muscle, freed as much as possible from fat, nerves, and vessels, yielded, when burnt, from 2 to 8 parts of ash, and that about 90 parts of this ash consisted of alkaline and earthy phosphates, and the remaining 10 parts consisted chiefly of chloride and sulphate of sodium. The muscular substance of the heart is remarkable for containing inosite, which is not found in other muscles. Living muscles consume oxygen, and excrete carbonic acid. By the oxidation of the nitrogenous material in muscle, creatin, creatinin, hypoxanthin, taurin, leucin, &c., are produced.

The development of striated muscular fibre has long been a subject of discussion, and by the upholders of a cell theory has been supposed to originate in an apposition of cells, or a deposition in their interior. Dr Wilson Fox is the last observer who has maintained this opinion (1865). But the careful investigations of Savory, confirmed by those of Lockhart Clarke, Braidwood, and Eckhard, have proved that they are formed by the coalescence of the molecular matter of the intercellular substance, several of the embryonic cells and nuclei remaining embedded in the substance of the fasciculus. (See Pl. IV. fig. 26, and description of plate.) This view once recognised, it may be observed, on consulting the accurate figures published by Schwann and Bowman, that the facts that they have placed on record are in accordance with the molecular origin of voluntary contractile fibre.

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* Kühne, Myologische Untersuchungen, 1860.

NUCLEAR FIBRES.—*Elastic or yellow fibrous tissue* is formed of nuclear fibres. They vary greatly in thickness, from the 1.10,000th to the 1.3000th of an inch in diameter. In the *ligamenta subflava* of quadrupeds they may frequently be seen to anastomose with one another (Pl. IV. fig. 3). In the giraffe, as pointed out by Quekett, they often present transverse markings, owing to small spaces in their substance. Their extremities have a tendency to curl up, and they may frequently be seen, as figured by Henle, forming distinct spirals, especially in the fibrous tissues at the base of the brain (Fig. 4). The addition of acetic acid produces no change in these fibres, so that they present the chemical reaction of the nuclei of cells. Their mode of formation, according to Henle, is from an elongation of the nuclei in neighbouring cells, which, coalescing together, and sending off branches which unite with one another, produce this anastomosing elastic fibre. The spiral he thinks is produced by the nucleus frequently being on the opposite sides of neighbouring cells, so that, in order to unite, they are obliged to cross and wind round the interior of the cell (Fig. 8). The spirals in the cells and ducts of plants are probably formed in a similar manner.

Chemical composition.—The chief proximate principle found in elastic tissue is elastin, which has been already described (p. 11).

Several fibres, evidently developed from a nucleus, possess contractility. The spiral or zig-zag fibre in the stalks of vorticellæ, the spermatozoid in animals (Pl. IV. fig. 12), and the antheroid moving particles in plants, are evidently of this kind.

CELL FIBRES.—*Areolar or white fibrous tissue* is the most characteristic example of this kind of fibre (Pl. IV. fig. 6). It consists of filaments, varying from the 1.16,000th to the 1.8000th of an inch in diameter, running in wavy parallel lines, in bundles, which often, by crossing one another, leave spaces or areolæ. In ligament and tendon, however, they are more condensed together. On the addition of acetic acid, they are for the most part rendered partially soluble, and very transparent, like the substance of cell walls. They are developed, as was shewn by Schwann, by the splitting up of cell walls (Pl. IV. fig. 9), the nuclei often remaining scattered among the fibrous bundles, and becoming very perceptible after the action of acetic acid, which does not affect them (Fig. 7). The various fibres found in the epidermic appendages of hair, horn, feather, &c., are developed in the same way, although a chemical change occurs in them, by means of which some of them are rendered insoluble in acetic acid (Fig. 10).

Although this is the usual method whereby the white areolar fibres are developed, I have no doubt that they may be occasionally produced by the splitting up of intercellular substance (Henle), or by superposition of molecular substance around the nucleus (*Epigenesis* of Robin).

Chemical composition.—Areolar tissue contains a large amount of water, and loses much of its weight by drying. It consists almost wholly of gelatin.

2. *The contractile cell fibres* are seen in the so-called non-voluntary muscular coats of hollow viscera (Pl. IV. fig. 13). Here the cells elongate into a fusiform or spindle-shaped body, and, flattening and uniting at their edges, form riband-shaped bands, of which the structure is made up. On the addition of acetic acid they are seen to be studded with oval or elongated nuclei (Fig. 14). Each individual cell has the property of shortening its length and swelling out laterally, thus producing contraction of the tissue. These same cells, isolated or grouped together, are the origin of contractions in various textures, such as the iris, the dartos, the uterus, &c. (see p. 68). In the last-named organ, during pregnancy, they are greatly enlarged, and, though not contractile previously, they assume that property for the purpose of expelling the fœtus, or other uterine contents—which accomplished, they undergo fatty or molecular histolysis and disappear.

Numerous other examples of contractility in cells may be observed among the infusoria, in the embryonic hearts of numerous animals, and especially in cilia, which must be regarded as a form of contractile cell fibres.

3. *Cilia* are contractile fibres resembling in shape the hairs of the eyelashes : hence their name. They are widely diffused in the animal kingdom, covering the bodies and respiratory organs, or surrounding the oval aperture in infusorial, molluscous, and other animals. In man they cover the lining membrane of the nasal passages, the Eustachian tube and cavity of the tympanum, the trachea and bronchi, the cavity of the uterus and Fallopian tubes, and the ventricles of the brain. Each cilium is like the blade of a sabre in shape, that is, flat and slightly curved, having a point and broad base where it is fixed (Pl. IV. fig. 16). They

are clear and structureless. When observed in action, they move backwards and forwards something like growing grain when agitated by the wind. Their vibrations, however, are more rapid, amounting to seven hundred in a minute. As the movements become slower, it can be seen that they beat the water broadways, and turn their edge, in coming back, like the action of feathering the oar by a boatman. They die from the base upwards, the top continuing to move sometime after the base is motionless. (Pl. IV. figs. 15 and 16.)

It has been supposed that each cilium is moved by two minute muscles inserted into its base (Ehrenberg); that it consists of a double spiral, which is continually winding and unwinding itself (Barry); or that it is due to imbibition of nutrient fluids (Beale). But neither muscles nor double spiral can be seen with our highest magnifying powers, and the peculiar and rapid to and fro movements in fluids are inexplicable on the supposition of imbibition. It must depend on an inherent power, the nature of which is essentially vital. (See Contractility.)

Histolytic Fibres.—The term histolytic may be applied to those fibres which result from a disintegrative process, such as may be seen in cartilage, where, as the result of molecular changes in the intercellular substances, it splits up and fibrillates, as seen in Plate VI. figs 3 and 4. It has been well figured and described by Redfern in the morbid changes occurring in joints. Such histolytic molecular changes occurring in cartilage may also be observed occasionally to give rise to histogenetic fibres, as takes place in many forms of fibro-cartilage, and in some of those productions denominated by Dr Handfield Jones, "fibroid degenerations,"—a fact which strongly supports the molecular theory of organisation and the alternate function of histogenetic and histolytic elements.

Function of the Non-contractile Fibres.—The molecular fibres of blood and mucin can only serve to give consistence to those fluids when exuded into tissues or collected on surfaces, and to entangle the cells together so as to favour their histolytic action. The nuclear or elastic fibres serve to connect joints, and to give greater firmness and elasticity to certain tissues. They restore parts after they have been moved by muscular action, and hence in various places they supply an antagonistic force to muscles. The areolar or cell fibrous tissue unites other elements, binds together groups of cells, offers an elastic medium permitting motion, and serves as a matrix to protect the blood vessels and nerves as they ramify through the frame. In tendons, it acts as the rope of a pulley ; in ligaments, as uniting joints ; in aponeuroses, as a firm membrane for the insertion of muscles ; and in integument and investing membrane, as a firm protective envelope to the body or to various viscera.

In recent times a new function has been ascribed to these fibrous tissues which here requires notice. Reichert was the first to group several of them together under the name of *connective tissues*, because they lie between and so far connect, or as Kölliker more correctly states, support, various histological elements. It was supposed that they were united together or continuous throughout the organism, and served as a substratum or basis tissue to all parts of the body. Kölliker so far differs from this view, as to consider that it is not so much their anatomical union as the genetical connection between them and their correspondence in function which keep them together. But when it is considered that these connective tissues are said to be the vitreous humour of the eye ; mucous tissue as it is found in the umbilical cord and in the lower animals ; the gelatinous tissues of the embryo ; the areolar and elastic tissues of the adult, with their various modifications, as observed in tendon, ligament, aponeuroses, &c. ; as well as the tissues of cartilage, bone, and even of tooth,—the idea of grouping them together, on the ground of either structure or function, seems most arbitrary. If the term connective tissue be limited to tendon, ligament, elastic or areolar tissue, which unite and connect together important parts, there can be no objection to its employment ; but to call a tooth, or the vitreous humour of the eye, also, connective tissue, can only lead to confusion of facts and ideas.

But Virchow has even still further extended this group of the connective tissues ; for, in addition to those previously named, he holds that fat, cornea, and the grey substance of the brain are also connective tissues. In this manner, connective tissue may be structurally fibrous in ligament, cellular in fat, hyaline in cartilage, and molecular in the grey substance of the brain. Chemically, it may be chondrin in cartilage, albuminous in tendon, horny in cornea, peculiar in elastic tissue, and mineral in bone. Hence the most diversified substances as to structure, chemical composition, and vital and physical properties are associated together. What other histologists consider solid fibres, Virchow regards as hollow tubes, and says they serve to convey a nutritive fluid to all parts of the economy. And again, what are almost universally thought to be nuclei, he maintains are cells (connective tissue cells), and declares them to be the origin of all healthy and morbid formations. This last view I shall again allude to. But with regard to the solid fibres of areolar and elastic tissue being tubes, an examination of a transverse section of a tendon will at once disprove the statement, for there the ultimate fibres of which we have spoken can be seen, with a sufficient magnifying power, to have no cavity, and, therefore, to be solid. It is true that the bundles of these fibres frequently have little spaces where they meet, with three or four angles having divisions leading between the bundles. These, as pointed out by Henle, explain the appearances in tendon referred to by Virchow, and account for the mistake he has committed.

We must conclude therefore that no such system of tubes as have been supposed by Virchow, exist in the fibrous tissues generally. In bone, certainly minute canals are visible, and we can see coloured fluids run into them. Nothing of the kind exists in the fibrous tissues, vitreous humour, or brain, nor is there any ground for belief that the nutrient fluids which permeate the tissues are derived from any other source than the blood vessels, or that these latter are assisted by a supplementary circulation. Dr Beale, after careful investigation of this subject, has arrived at the same conclusion.

Function of Contractile Fibres.—The nature of contractility as a vital action will be subsequently considered. (See Vital Properties of the Tissues.) Here it is only necessary to point out that the textures endowed with it, when stimulated, either directly or indirectly, first contract in consequence of a closer aggregation of the molecules of which they are composed, and subsequently relax, when they return to the condition which characterised them when at rest. This power is utilised in the animal economy in various ways. In the lowest forms of animal and vegetable life, it permits of change of place, by causing serpentine, or alternate movements, which, overcoming the force of resistance in fluids or solids, permits of locomotion. In cilia, a similar result may take place if they are attached to small bodies, but if fixed to large ones or extended surfaces, they induce currents in the fluids which cover them. In isolated nuclei, or cells scattered through the skin, it induces contractions, puckerings, erections of the hair or feathers. When the tissue is arranged in layers, as in the iris or round hollow viscera, it induces contractions and dilations in apertures or organs. In the voluntary muscular system generally, when co-ordinated by the nerves and nerve centres, it occasions reflex and voluntary movements. All kinds of contractility may be excited by direct irritants, while some act in obedience to certain nervous influences, and others to different ones. The voluntary muscular fibres possess contractility in the highest degree, and hence their study, as influenced by varied conditions, is one of the greatest importance.

Effects of irritants on muscles.—Some substances easily cause contraction of muscles when applied directly to them, even if greatly diluted ; whereas to produce the same effect through the nerves, they require to be concentrated. Among these are —the mineral acids, especially muriatic and nitric acids ; the basic salts, as chloride of sodium, chloride of potassium, chloride of lime ; as well as some organic substances, as acetic acid, lactic acid, and glycerine. A second class of substances induce contraction equally, whether applied to the nerve or to the muscle. Among these are caustic potash and soda. A third class of chemical substances act powerfully on the muscle, but not at all upon the nerve ; such as chromic acid, sulphate of copper, chloride of iron, basic and neutral acetate of lead, lime, and, above all, ammonia. A fourth class of substances act exactly in an opposite manner—that is, upon the nerve, but not on the muscle, or very slightly so ; such as creasote, alcohol, concentrated glycerine, and undiluted lactic acid. Finally, a fifth class exists which have no power of producing contraction when applied to either muscle or nerve ; such as the fatty oils and turpentine.* When the sensibility of the muscular nerves has been quite destroyed in various ways, it was shewn by Wittich that contractility could be powerfully induced on injecting water into the blood vessels.

The amount of contractility in different muscles is influenced

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* See Kühne in Archiv. f. Anat. und. Phys. 1859.

—supposing them to be equally contractile and healthy—by the amount of resistance they have to overcome, and by their static force. In the individual muscles of animals this can be determined with exactitude by hanging to them different weights, causing them to contract suddenly by galvanism, and marking off the result by means of Pflüger's myographion. (See Practical Physiology.) The efforts of particular muscles when performing complex actions, however, it is very difficult to estimate.

Effects of poisons on muscles. -Strychnine, as is well known, excites powerful tetanic spasms in muscles. Coniene causes paralysis, which, in man, has been shewn to commence in the lower extremities and proceed upwards.* Other poisons influence more especially particular muscles : such as aconite, which operates on the heart ; lead, on the extensors of the arms ; cantharides, on the urinary bladder ; secale cornutum, on the pregnant uterus, &c. Bernard shewed that with curara the motor nerves might be paralysed without affecting the muscular contractility ; and Kölliker has demonstrated that veratrine destroys the contractility without affecting the motor nerves. Both poisons operate through the circulation. These facts serve to confirm—although in no way necessary—the Hallerian doctrine of irritability.

Evolution of electricity by muscles.--All muscles evolve a constant stream of electricity, which may be shewn by a multiplying galvanometer to pass from the long external surface, which is positive, to the transversely cut section, which is negative. This current is strongest in inactive muscles, because when stimulated to contract, the intensity of the current is sensibly diminished. (See Animal Electricity.)

Effects of electricity on muscles.—If a continuous stream of electricity is sent through a muscle, contractions take place at the moment of opening and shutting the circuit ; otherwise no effect is produced. These contractions are the more powerful the less the muscle is fatigued. One electrical shock sent through a muscle may last only the one-thousandth part of a second. The contraction of the muscle produced does not occur so rapidly, but reaches its maximum and returns to its former state in one-fourth of a second. If two shocks are given, the second immediately after the muscle has returned to a state of rest then there are two contractions. If the second shock is given during the operation of the first, and the muscle is either shortening or lengthening, it causes increased shortening. But if the second stroke follow very rapidly on the first—that is, within the six-hundreth of a second—the shortening is not greater than with one stroke. If several shocks are given before a muscle has time to be relaxed, it becomes hard and permanently contracted, constituting *tetanus*. (See Practical Physiology.)

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* See the Author's Case of Poisoning by Hemlock, "Principles and Practice of Medicine," 5th edition, p. 459.

Muscular fatigue.—The stronger the contractions, the oftener they are repeated, and the greater the resistance muscles overcome, the sooner are they fatigued. Much also will depend on the general nutrition of the economy, and on conditions connected with the motor and sensory nerves. Thus the muscles of a strong man are not so easily fatigued as those of a weak one. In fever, the muscles, without any exertion, reach the greatest degree of fatigue or weakness.

Cadaveric rigidity is characterised by loss of contractility, elasticity, and of electro-motor power. Its cause is now generally attributed to the coagulation of the muscular substance, which in the living body is partly fluid (Brücke). It commences in the neck and pharyngeal muscles, then passes to those of the face, then to the upper extremities, the trunk, and lastly to the lower extremities. The heart is rigid very early. The time of its duration varies greatly, and occurs from a quarter of an hour to eighteen hours after death. It may last from some hours to five or six days. The longer it is in appearing, the longer generally it lasts. It is often very slight, and after death, in animals long driven, or dying after being chased, or from severe convulsions and certain poisons, or killed by lightning, it is scarcely perceptible. The disappearance of the rigidity takes place in the same order as it came on, that is, from above downwards. On its cessation, putrefaction and real death of the tissues commences.

The Tubular Elements of the Tissues.

Definition.—By a tube is understood, as an element of the textures, a microscopical filament composed of a wall and contents. Optically it is distinguished from a fibre by one or two thin lines on each side, gradually passing into a broad light space in the centre.

Varieties of tubes.—These are numerous in plants, where they constitute the various ducts—simple, dotted, reticulated, spiral, and scalariform—and laticiferous tissue. In animals we may divide them into Air, Blood, Dental, Bone, and Nerve Tubes.

AIR TUBES.—The larger air and blood tubes, such as the trachea and bronchi on the one hand, and the large arteries and veins on the other, must not be regarded as elementary tubes, but as hollow viscera, being composed of various laminæ or coats. Their ultimate ramifications, however, become more simple. The air tubes are strengthened in the higher animals with rings or nodules of cartilage, so as to keep them permanently open ; and in the lower animals, especially insects, as in plants, they present a spiral fibre in their interior, so that they are always patent. (See Respiration.)

BLOOD TUBES.—A minute examination of the blood vessels, including the lymphatics and lacteals, has enabled the histologist, following Henle, to demonstrate in them one or more of the following layers. These, as seen in a larger artery, may be enumerated as follows, from within outwards,—

1st. The internal layer presents all the characters of pavement epithelium, the cells varying in shape, and being occasionally fusiform.

2d. The next layer is a transparent, delicate, and fragile membrane, which easily rolls upon itself. It is distinguished by long, occasionally branched nuclei, running transversely, with round or oval openings of various sizes perforating the layer. It is called the striated, perforated, or fenestrated membrane, and is occasionally absent (Plate. V. fig. 2, *a*).

3d. The third layer is characterised by longitudinal lines which are in no way changed by acetic acid. It is formed of one or more layers (Plate V. fig. 3, *a*, *a*, and fig. 6, *t*, *t*, *t*).

4th. The fourth layer is distinguished by short transverse lines, which alternate with each other. It is much developed in large vessels, and constitutes, with the third layer, what is called the middle coat (Plate V. fig. 3, *b*, *b*, and fig. 6, *b*, *b*).

5th. The fifth layer is only found in the larger vessels, and is simply yellow elastic tissue (Plate V. fig. 4).

6th. The sixth layer is composed of white areolar tissue, the fibres of which are arranged longitudinally, having scattered here and there among them persistent nuclei (Plate IV. figs. 6 and 7).

The satisfactory separation and demonstration of these different layers requires great care. Some are better seen in the arteries than in the veins, or in vessels of a particular size. A little experience, however, will satisfy the observer of the correctness of Henle's description.

As the blood-vessels are traced towards their capillary terminations, they gradually lose their elastic and areolar coats. In small arteries, we see them almost wholly composed of fusiform cells, arranged in two layers, longitudinal and circular. (Pl. V. fig. 3). Sometimes these cells assume a spiral form round the internal layer, as shewn by Mr Lister (Fig. 5). At other times they blend together (Fig. 2), and in the ultimate capillary we observe only a simple membrane, having oval nuclei imbedded in it (Fig. 1). Such membrane is admirably fitted to permit of transudation through it of the nutritive fluid essential for the maintenance of the animal structures.

Contractile movements of blood tubes.—The blood tubes are evidently contractile, and capable of diminishing or enlarging their calibres under the action of various stimuli, such as mechanical and chemical irritants on the one hand, and peculiar nervous influences on the other. Thus, friction, cold, chemical astringents, and warmth produce pallor or redness of the surface, and similar effects are occasioned by the mental emotions of fear and shame. Mr Lister was the first clearly to demonstrate on the minuter arteries contractile fibre cells, to which he attributed the effects, and to these only he limits the contractile property. I am satisfied, however, from many careful observations, that this property especially belongs to the ultimate capillaries, which I have seen, under stimulation, diminish to one half their calibre, so as to squeeze out and prevent the re-entrance of the coloured corpuscles. The experiments of John Hunter led him to conclude that the elastic property is strongest in the large, and contractility strongest in the smallest vessels, an opinion which the more minute histological observations of modern times have proved to be correct.

The development of blood tubes may be readily followed in the vascular layer of the germinal membrane, and in certain serous exudations, where the cells may be seen of a triangular or varied shape, throwing out processes to unite with one another and form a capillary plexus (Pl. V. fig. 7, *a*, *d*, *e*, *f*). Subsequently, fusiform cells can be observed aggregated around them to produce the different layers (Fig. 7, *c*, *b*).

The function of the blood tubes is to permit the blood to be distributed to all parts of the organism. The coloured or red blood passes out by the arteries and inwards by the veins. The capillaries or intermediary vessels so subdivide it as to permit the corpuscles to carry oxygen to the tissues, and these last to effect exchanges between themselves and the blood. The delicate homogeneous structure they present admirably fits them for acting as fine filters subject to vital laws, retaining the solid corpuscles and granules, and allowing only the fluid portions to transude. The lymphatics and chyle vessels convey the colourless or white blood from the tissues and alimentary canal towards the large veins in the neck, where they join the circulation near the heart, a function in which, like what occurs in the veins, they are greatly assisted by the numerous valves in their interior.

DENTAL TUBES.—On making a section of a tooth, it is seen to consist, 1st, internally of a *pulp* which is richly supplied with blood vessels and nerves ; 2d, of the *ivory* or *dentine*, constituting the chief bulk of its substance ; 3d, of *enamel*, which forms a layer over the crown ; and 4th, of the *crusta petrosa* which surrounds the root.

The pulp consists of fat cells, united together by a small amount of areolar tissue, among which a rich plexus of blood vessels are distributed and numerous terminal loops of the dental nerve.

The ivory or dentine is a firm substance, consisting of an animal basis impregnated throughout with phosphate of lime. On examining a thin section of it under magnifying powers, minute tubes are seen radiating through it, and passing from the central cavity to the circumference (Plate V. fig. 10, *a*). They are about the 1.10,000th to the 1.5,000th of an inch in diameter, run in parallel lines, and occasionally send off lateral branches. They terminate abruptly at the line of junction between the dentine and enamel above and dentine and crusta petrosa below. A transverse section shews them to possess a distinct wall, with a space in the centre (Fig. 9). Mr Tomes describes a pulpy substance as filling these tubes, which he considers to be nervous in its nature. But, as stated by Dr Beale, it is more probably coagulated nutritive matter.

The enamel, at one time tubular, in the adult is composed of solid prisms, the phosphate of lime having invaded every available space. It is therefore harder,—containing more mineral and less animal matter,—than dentine. On making sections through it in various directions the solid prisms may be seen running vertically outwards in straight or wavy lines (Plate V. fig. 8, *a*). A perfectly transverse section shews them to be closely compressed together, and of an hexagonal form (Plate V. fig. 11).

The crusta petrosa is in fact a layer of bone which surrounds the root of the tooth (see Bone). (Pl. V. fig. 10, *b*.) When young, this texture may frequently be seen to be forming, by the apposition of rounded solid masses, formerly called bone cells, in the centre of which is a nucleus or cavity, that constitutes the lacunæ of the structure (Plate V. fig. 12).

Chemical composition of Tooth.—The dental tisues consist of certain inorganic matters united with an organic basis. In crusta petrosa the organic basis is the same as that of bone. The organic matter of dentine is resolved by prolonged boiling into gelatin, while that of enamel does not yield gelatin, but a substance allied to the chemical basis of epithelium.

The proportion of inorganic to organic matter, and the composition of the former will be seen from the following analyses by Von Bibra.*

	Phosphate of Calcium and Fluoride of Calcium.	Carbonate of Calcium.	Phosphate of Magnesium	Salts.	Inorganic Matter.	Fat.	Organic Matter.
Enamel—							
Man, molar	89·82	4·37	1·34	·88	96·41	·20	3·59
Woman, molar	81·63	8·88	2·55	·97	94·03	Trace	5·97
Horse, molar	89·01	1·19	1·95	·60	92·75	·19	7·25
Dentine—							
Man, molar	66·72	3·36	1·08	·83	71·99	·40	28·01
Woman, molar	67·54	7·97	2·49	1·00	79·00	·58	21·00
Ox, incisor	58·33	7·39	0·97	·75	67·44	·52	32·56
Crusta petrosa—							
Ox, incisor	58·00	7·22	·99	·73	66·94	·95	33·06
Whole teeth—							
Pike	63·98	2·54	·73	·97	68·22	1·18	31·78

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* Von Bibra. Chem. Untersuch. über die Knochen u. Zähne. 1844.

The function of these different textures in a tooth is evidently to combine firmness and hardness with the power of keeping up nutrition. The enamel resists pressure and the friction necessary in the act of mastication. Through dentine tubes the nutritive matter is conveyed from the vascular pulp to all parts of its substance, while the softer crusta petrosa firmly wedges the tooth in its socket, and diminishes the effects of jars and concussions. Where, in the teeth of the lower animals, two or more of these substances reach the surface, attrition acts upon them differently, keeping the edges of the incisors sharp, as in the rodentia, or the surface rough, as in the graminivora.

Bone Tubes.—Though the osseous, like the dental texture is characterised by its tubular arrangements, the complex structure it presents renders its classification difficult. Cartilage is essentially a cellular tissue, yet its relation to bone forces upon us the necessity of describing them together in this place.

Cartilage or gristle is an opaque, non-vascular substance of pearly or bluish white colour, approaching towards yellow. It is easily cut with a sharp knife, yet possesses tolerable density. It is highly elastic, and in thin slices is translucent. In the early embryo and young animal, the skeleton is mostly cartilaginous, and is afterwards transformed into bone. Such cartilage is called *temporary*. *Permanent* cartilage covers the articular surfaces of joints, and is present in the costal cartilages, the external ear, the extremity of the nose, eyelids, the Eustachian tube, the larynx, and the trachea. In all these situations considerable firmness, united to elasticity, is given to the parts, although they become more rigid as life advances towards old age. The structure somewhat varies in articular, costal, and fibro-cartilage.

Articular Cartilage.—A thin section cut parallel with the surface of a joint consists of rounded or oval isolated cells embedded in a semi-translucent hyaline substance. If cut vertically with the joint, the cells, as they approach the bone, may be seen to arrange themselves in groups of twos and fours, sometimes side by side, at others, lengthways (Pl. VI. figs. 1, 9, *b*, *c*, *d*, *e*, *f*). The cells are nucleated often with nucleoli, and present great varieties in size and development. They are unaffected by re-agents. The hyaline or intercellular matter presents no structure under ordinary circumstances, but when diseased exhibits a tendency, first to become opaque and molecular, and subsequently fibrous.

Costal Cartilage.—A transverse section of costal cartilage always displays a point of ossification in its centre similar to what exists in fœtal bone (Pl. VI. fig. 11). Towards the circumference, isolated cells may be seen embedded in the clear intercellular substance, but towards the bony centre they may be seen to arrange themselves, first in groups, and then in rows radiating from that centre. A section of the structure at this point exhibits the primary changes of cartilage passing into bone (Plate VI. figs. 12, 13, 14).

Fibro-Cartilage is well seen in intervertebral substance, the epiglottis, and cartilages of the ear. The intercellular substance in this case is composed of fibrous tissue, and the greatest diversity may exist as to the respective amount of cells and fibrous elements in various places. There may be many cells and few fibres, or nearly the whole texture may be fibrous, and the cells few and far between (Plate VI. fig. 3).

Fœtal Cartilage.—In the early embryo, cartilage is mostly cellular, the hyaline substance increasing in amount and separating the cells as development proceeds. The same modifications in structure are observable in the lower animals, as in the ear of the bat and mouse, in the cuttle-fish, lamprey, &c., &c. The changes which occur in fœtal cartilage on its transformation into bone will be subsequently described.

Diseased Cartilage.—When cartilage is injured or irritated, both the cells and hyaline substance undergo marked alteration (Redfern). The former enlarge, new cells form in the interior by division and subdivision of the nucleus (proliferation), and tertiary, or even quaternary cells may be formed within this (Plate VI. fig. 9, *g*, *h*). On the distension of the original cell wall, by the young included cartilage cells, the former may burst, liberating the secondary or tertiary cells. These diffuse themselves in the intercellular matter which becomes swollen and pulpy, and subsequently breaks down, producing the degenerations and abrasions so characteristic of diseased cartilage (Fig. 5). The hyaline or intercellular matter at the same time, first becomes turbid and opaque, and then splits up into fibres, which add to the disintegration process in the tissue, causing the villous changes on the surface, characteristic of chronic white swellings of a joint (Plate VI. figs. 4, 8). Hypertrophy of cartilage, especially in the form of tumour, is called *Enchondroma.*

Chemical Composition of Cartilage.—About sixty parts in the hundred of permanent cartilage consists of water. By prolonged boiling in water, cartilage is resolved into chondrin, which gelatinises on cooling. The gelatinous mass also contains gelatin derived from the fibrous tissue which is usually associated with cartilage. The temporary cartilages are resolved by boiling into a substance resembling chondrin, but differing from it in not congealing when allowed to cool. The ash of cartilage consists of carbonate of soda, sulphate of soda, carbonate of lime, and other salts, the relative proportion of which will be seen in the following analysis by Frommherz and Gugert * :—

Analysis of Ash of Cartilage—100 *parts.*

Carbonate of soda,	35.07
Sulphate of soda,	24.24
Chloride of sodium,	8.23
Phosphate of soda,	0.92
Sulphate of potash,	1.20
Carbonate of lime,	18.37
Phosphate of lime,	4.06
Phosphate of magnesia,	6.91
Oxide of iron and loss,	1.00
	100.00

Bone.—On making a longitudinal section of a long bone, and examining it with a low power (20 diameters), it presents the appearance represented, Plate VI. fig. 6. That is canals running lengthways, and freely communicating with one another, embedded in a finely dotted structure. These canals are those of Havers. On now examining the same structure with a higher power (200 diameters), we observe the appearance represented, Fig. 8. The canals, of course, are larger to the eye, but the dots appear as oval or fusiform opaque spots, with fine lines radiating from them and connecting these spots with one another. These are the *lacunæ* of bone, rendered opaque by the debris or sawdust produced by grinding the preparation, and their connecting *canaliculi.* If now we look at a transverse section of the same bone, magnified 200 diameters, as in Fig. 7, we see the large openings which are the Haversian canals cut across, sometimes clear, at others opaque from accumulated and adherent sawdust. The arrangement of the lacunæ in concentric circles round these canals is also observable, the canaliculi of the internal row communicating with the large Haversian canal, and the others with successive lacunæ until the terminal or external row is reached. It is thus demonstrated that there is a channel of communication between the vascular lining membrane of the Haversian canal, through the minute tubes or canaliculi and lacunæ, to the distant concentric circles of each system pervading the osseous texture.

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* Quain's Anatomy, 7th ed. Vol. I. p. lxxxiv.

The lacunæ, with the tubes or canaliculi leading from them, vary considerably, in form and length, in various parts of the osseous texture, and especially in the bones of different animals. The lacunæ in man are of fusiform shape, and have an average length of 1.1800th to 1.2000th of an inch in length, and they are usually half as long again as they are wide. The variations, however, that may exist in their size and forms, as well as in the arangement and differences in the canaliculi, are shewn, Pl. VI. Fig. 10, *a*, *b*, *c*. *d*, *e*. The general mode of the communication between the lacunæ is seen in Fig. 10, *f*.

The hardened tissue between the lacunæ and canaliculi, is supposed by Sharpey to be composed of crossed fine reticular fibres, which is probable, though difficult to demonstrate. Tomes thinks it is made up of very fine earthy molecules agglutinated together. Both opinions may be conjoined, for as the intercellular substance of cartilage is the basis of bone, and this, as shewn by Leidy, has a fibrous arrangement, the fine mineral molecules of phosphate of lime deposited in it must make up the ultimate osseous tissue. Quekett endeavoured to shew a relation between the size and form of the osseous lacunæ and that of the blood corpuscles in different animals, an idea which, though correct in some reptiles, fails in others as well as in birds.

Bone is nourished by a plasma derived from the plexus of vessels ramifying on the lining membrane of the cancelli and Haversian canals. This, in its turn, is supplied by a special artery. Bone, indeed, may be regarded as mineral substance deposited between the meshes of vascular capillaries. The canaliculi and lacunæ, by presenting minute tubes with dilatations, present the best possible arrangement for the distribution of a nutritious fluid, which, from the slowness of its movement, will readily permit of mineral precipitation.

Bone also contains nerves, which accounts for the pain originating in them in cases of rheumatism, syphilis, malacosteon, and other diseases.

Chemical Composition of Bone.—Bone consists of an organic substance called bone cartilage or ossein, impregnated with earthy matter composed of various inorganic salts, the chief of which is tribasic calcium phosphate, calcium carbonate, and calcium fluoride. The earthy matter may be separated from the bone cartilage by macerating a bone for several days in dilute hydrochloric acid. The salts are gradually dissolved out, and the cartilage is left as a soft translucent mass, retaining the form of the bone. Another mode of analysing bone is to incinerate it till it becomes white. The organic matter is thus burnt off, and the ash may then be analysed. The composition of bone cartilage, according to Von Bibra* and Frémy,† is as follows :—

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.
From femur of ox .	50.13	7·07	18.45	24.35
From calf . . .	49.9	7.3	17.2	25.6
From rib of river carp	50.32	7.22	18.42	24.00

The following table shews the per centage of inorganic matter in human bones of various ages, according to Von Bibra.‡ It will be observed that the proportion of inorganic matter in bone is generally smaller in youth than in age :—

Name of Bone.	Per centage of Ash.	Name of Bone.	Per centage of Ash.
Male fœtus, 7 mths.		*Woman*, 25 years	
Femur, tibia	59.1 to 59.6	Femur, tibia	68.4 to 68.8
Boy, 9 months		Humerus .	69.25
Femur . .	56.43	*Man*, 30 years	
Humerus .	58.58	Femur, tibia	68.0 to 69.4
Boy, 5 years		*Man*, 58 years	
Femur . .	67.80	Femur . .	68.53
Girl, 19 years		*Woman*, 78 years	
Femur . .	67.85	Femur . .	66.81

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* Von Bibra, *Op. Cit.*

† Frémy, *Ann. Chimie Phys.* [3] xlvii.

‡ Von Bibra, *Op. Cit.*

According to Frémy, the bones of all the mammalia shew the same average composition as those of man, but the bones of herbivorous animals generally contain a larger proportion of lime salts than those of flesh-eaters. The following table, modified from Frémy,* shews the comparative analyses of bones belonging to different orders of the animal kingdom :—

Name of Bone.	Ash per cent.	Phosphate of Calcium.	Phosphate of Magnesium.	Carbonate of Calcium.
Woman, 22 years, cranium	64.1	57.8	1.7	10.9
Man, 40 years, femur .	64.2	56.9	1.3	10.2
Egyptian mummy, femur .	65.0	58.7	1.7	5.9
Lioness, femur .	64.7	60.0	1.5	6.3
Rabbit, femur . . .	66.3	58.7	1.1	6.3
Elephant	66.8	62.2	1.2	5.6
Horse, femur . . .	70.4	60.5	1.7	7.9
Ox, humerus . . .	70.4	61.4	1.7	8.6
Eagle	70.5	60.6	1.7	8.4
Chicken	68.2	64.4	1.1	5.6
Tortoise (carapace) . .	64.0	56.0	1.2	10.7
Carp	61.4	58.1	1.1	4.7

Transformation of Cartilage into Bone.—We have seen that near the osseous centre the cartilage cells are arranged in long groups or rows. This is especially observable in fœtal bone. (See Plate VI. figs. 11, 12, 13). It is between the groups of cells that we can see the mineral molecules of phosphate of lime deposited (Fig. 12, *b*, 13, *c*). These at length, by their aggregation, assume a linear arrangement, and form ridges of calcareous matter that extend between and surround the rows of cells, which now become first compressed together and then melt into one another, leaving open spaces (cancelli) or tubes (Haversian canals). The nuclei of these cells become embedded in the advancing ridges of bone, and form the lacunæ (Plate VI. fig. 12, *c*, *b*). Within the primary spaces and tubes so formed, however, the broken down cell walls form a secondary or hystolitic mass of molecules, from which new cells are formed that are developed into fibres and blood-vessels in the same manner that these structures are produced in the embryo. These ultimately constitute the living vascular membrane of the cancelli and tubes. As soon as a circulation of blood is established through them, nourishing matter is given off more regularly as from a centre, and thus the Haversian canals become surrounded by nucleated cells arranged in concentric series. As these become infiltrated with mineral matter, the nuclei are not invaded, but remain as open spaces or lacunæ, whilst between these and the limits of the cell walls, minute channels are left, which are the canaliculi. In the same manner, a regular deposition of phosphate of lime in a nucleated texture may produce bone in fibrous tissues—not cartilaginous—such as tendon, periosteum, the arachnoid membrane, &c., which structures it is by no means uncommon to find converted into bone.

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* Frémy, *Op. Cit.* Traité de chimie par Pelouze et Frémy, 2nd ed.

The regeneration of bone after fracture takes place in the consolidated clot or exudation which collects around the broken extremities. The blood corpuscles and serum are first absorbed, a fibro-cellular substance is formed resembling fibro cartilage, the cells arrange themselves in rows from the nearest ossifying centre, and phosphate of lime is precipitated between them, exactly as it is in fœtal cartilage, and so bone is produced. To this end the vascular apparatus, as furnishing this nutritive matter, must be regarded as all important. Every tissue in the neighbourhood capable of furnishing such necessary substance, assists in the formation of new bone, and not, as was formerly thought, only bone or only periosteum. It has been shewn by Ollier that so long as the tissue of bone retains its vitality, it may be removed from one animal to another, or transplanted to various parts in the same animal, and not only continue to live, but increase in bulk.

THE NERVE TUBES.—A nerve is made up of a greater or less number of minute tubes. These are composed externally of a delicate membrane, called the *neurilemma* of the nerve tube (Pl. V. fig. 16, *a*). Inside this is a transparent, semi-solid, and peculiarly plastic material, called the *white substance of Schwann*. This, in its turn, encloses a viscous fluid. On mechanically breaking up these tubes, the white substance of Schwann—which, in the fresh structure, is characterised optically by two distinct lines, with a clear central streak on each side of the tube—(Fig. 13, *a*) has the property of rolling itself into globules or corpuscles of varying size and shape (Fig. 17, *a*). Each of these is characterised by the double line externally, and I have frequently produced them by squeezing the white substance of Schwann out of the investing sheath or neurilemma, and have seen them under the microscope rapidly unite at their two extremities. By gently pressing these tubes also, when separated in a perfectly fresh nerve, the semi-fluid contents can be forced out of their extremities, and made to coagulate on the glass slide, outside the open mouth of the tube (Plate V. fig. 19, *a*). In the perfectly fresh tube I have never succeeded in seeing a central band or axis.

These tubes vary greatly in size, being largest in the cerebro-spinal nerves, generally reaching the one-thousandth of an inch in diameter (Fig. 13); they are smaller in the spinal cord (Fig. 14), and smallest in the white substance of the cerebral hemispheres (Fig. 18). In these two last situations, also, they present various enlargements, which I think are also post-mortem phenomena, the neurilemma being of exceeding tenuity, and easily stretched by the pressure of the covering glass when demonstrated under the microscope (Figs. 14, 17, 18). As they approach the periphery of the cerebrum and cerebellum, they become finer and finer, and are lost among the molecular grey substance in the one case, and the internal granular layer in the other. It has been supposed by several German anatomists that these nerve tubes are bound together by fibrous tissue. But careful examination has satisfied me that the supposed fibres are often minute tubes or the fibrillated substance of Schwann (Fig. 15). I have found, when a perfectly transverse section of the spinal cord is examined, in the carefully prepared specimens of Lockhart Clarke, with Ross's lens of the one-twelfth of an inch, that the tubes diminish in size until they resemble the smallest molecules; but when so minute as the sixteenth thousandth of an inch in diameter, I have distinctly seen the delicate external circle and central solid coagulated coloured rod (fig. 21). In the same manner, therefore, I believe, as histologists have hitherto failed to reach with their instruments the ultimate molecule in nutritive fluids, or the ultimate fibril in muscle, so they have not yet seen the ultimate tube in nervous matter.

Effects of reagents.—When any coagulating agent is added to the nerve tube—even water—the fluid contents are immediately solidified (Figs. 15, 20,) and, if long steeped in chromic acid, appear in the form of a solid rod, which runs down the centre of the tube. This is the *band of Remak*, or *axis cylinder of Purkinje.* It has, like the nuclear elements of the textures, peculiarly the property of being coloured by ammoniacal solutions of carmine, when it is easily shewn to be continuous with the contents of the nerve cell, and its course can be traced with great exactitude (Pl. III. fig. 18, *d*, *e*, *b*). Coagulating agents also cause longitudinal fibrillation of the white substance of Schwann round the axis (Pl. V. fig. 15), forming concentric circles when viewed in tranverse section (Figs. 20, *b*, 21). The prepared specimens of Mr Lockhart Clarke have never been surpassed in beauty, and they have led, in his hands, to most important discoveries. At the same time, it is my belief, from prolonged careful investigation into the structure of the nerve tube, that, as no central axis can be demonstrated in the perfectly fresh tissue, its existence is altogether a post-mortem phenomenon.

Chemical composition of Nerve.—This department of physiological chemistry is still in obscurity. The reaction of living nerve is neutral, but after strong action, according to Funke, it becomes acid. White nervous matter, which is composed chiefly of nerve tubes, contains less water than the grey matter, but it contains more fat. The semi-fluid substance, forming the axis cylinder, is believed to belong to the same series of chemical compounds as fibrin and syntonin, and is probably united with oily matter. The substance constituting the medullary substance seems to be some sort of soluble albumin.

Functions of the Nerve Tube.—The nerve tube possesses the property of generating and conducting an influence in different directions on receiving impressions from various stimuli. The impressions may result from the contact of the physical agents producing light, sound, touch, sapid bodies, and odours. But there are, doubtless, numerous other tubes peculiarly qualified to receive other impressions which may give rise to peculiar sensations, such, for example, as those of cold or warmth, of weight, of hunger and thirst, and of numerous other feelings, which, although not yet actually discovered, must have relation to the special endowments of these tubes. It has been clearly determined that while the optic and auditory nerve tubes have the property of conducting the influences produced by special impressions, they have not the power of transmitting others. In the same manner with regard to the directions in which these influences travel, a particular nerve tube would appear to conduct only in one direction. The directions at present known are, 1st, from the brain to the voluntary muscular system generally ; 2d, from the surface and the external organs of sense to the brain ; 3d, from one side of the body to the other through the spinal cord ; 4, from the cerebro-spinal system through ganglia to numerous glands, non-voluntary muscles, the blood-vessels, and the tissues generally. There may be other directions through which nervous influence travels by special nerve tubes, but such have not yet been discovered. In the meantime, we know that the nerve tubes are not only idio-motor and sensitive (general and special), but diastaltic, secretory, nutritive, and vaso-motor, and that a nerve may be made up of one or more of these different kinds of tubes, and thus be simple or complex in its action. (See function of innervation.)

Evolution of Electricity in Nerves.—Du Bois-Reymond discovered that, like muscles, nerves possess an electrical current, but much weaker, running from the longitudinal external surface, which is positive, to the transverse internal one, which is negative. (See Animal Electricity.)

Effects of Electricity on Nerves.—Du Bois-Reymond has shewn that when a portion of nerve is traversed by a current of electricity, it is thrown into a peculiar state, called an *electrotonic state*, which will be fully described when treating of Animal Electricity. It has also been shewn that the further a motor nerve is irritated from the muscle the greater is its excitability and its influence on the muscle, which is the very contrary of what was formerly supposed to be the case. Other remarkable facts as to the excitability of nerves when stimulated by electricity, are the result of the incessant labours of the present Berlin school of physiology, with Du Bois-Reymond at its head. They are largely adding to our knowledge of the functions of the nervous system. As to the theories put forth concerning the nature of nervous action, it will for the present be sufficient to say, that they consist in attributing the changes which occur, to alterations in the position and forces of the ultimate molecules of the nerves. (See Animal Electricity).

These researches point out to us that the vital properties of nerves, as of other tissues, are correlative, and that excitability, like contractility, when employed, is at the expense of electricity. Hence the vast importance of temperature, moisture, the electrical condition of the atmosphere, and other general causes, to the integrity of the nervous system. The influence of electrical currents on nerves, also, when further studied, serves to explain numerous facts long recognised during storms, such as the restlessness of cattle, the so-called sportiveness of fish, increased irritability of insects, and even in man the rheumatic, neuralgic, cerebral, and other phenomena which occasionally then appear in nervous individuals. The excited or depressed condition of some persons in good or bad weather, may also be thus explained, and the whole inquiry lead to more exact and useful principles in the application of electricity, as a therapeutic agent.

GENERAL CONCLUSION AS TO THE MOLECULAR THEORY OF ORGANIZATION.

If now we take a general view of the structural relations of the tissues, we observe that the molecular, cellular, fibrous, and tubular elements, are more or less mingled together, but that some tissues abound in one, and others in another. Thus the molecular element abounds in the nutritive fluids, in voluntary muscle, and in the grey substance of the cerebral convolutions; the cellular element abounds in adipose, in glandular, and in epithelial tissues; the fibrous element in areolar texture, ligament, tendon, and muscular tissues; and the tubular element in brain, spinal cord, bone, tooth, and throughout the body in the form of minute ducts, nerves, and blood-vessels. They all, as we have seen, serve general purposes in the economy. The molecular may be regarded as nutritive, or, as Dr Beale has called it, germinal matter. The cells serve to elaborate this matter for secretion, excretion, and certain kinds of growth. The fibres connect parts together, and in the molecular form of muscular fibre, present the highest degree of contractility. The tubes conduct nutritive fluids, and the nerve tubes that influence which is capable of exciting action in brain, voluntary muscle, glands, and vessels, by bringing each in connection with one another, or under the control of mind.

We perceive further, that those actions which are peculiarly vital, such as growth in certain directions, the power of contractility, and the existence of sensibility, are not, as some have supposed, the peculiar attribute of any one peculiar element of the textures, such as of cells or nuclei. I regard one and all as possessing powers which are necessary for the wellbeing of the economy, and each as reacting for the common welfare on one another. Thus, growth may be molecular, cellular, fibrous, or tubular. Contractility and spontaneous movements may be present in each of these elements ; and sensibility unquestionably is shared by nervous matter, at least in its molecular, cell, and tubular forms.

As to development, the molecular is the basis of all the tissues. The first step in the process of organic formation is the production of an organic fluid ; the second, the precipitation in it of organic molecules, from which, according to the molecular law of growth, all other textures are derived, either directly or indirectly. (See p. 45.)

When we investigate the functions of plants and animals—for example, generation, nutrition, secretion, motion, and sensation, we find them all necessarily dependent on the permanent existence and constant formation of molecules. Thus generation, both in plants and animals, is accomplished by the union of certain molecular particles called the male and female elements of reproduction. Among the *Protophyta*, the conjugation of two cells enables their contents, or the *endochrome*, to mix together. This endochrome is a mass of coloured molecules, and the union of two such masses constitutes the essential part of the generative act. In the *Cryptogamia*, a vibratile antheroid particle, enters a germ cell, and finds this last filled with a mass of molecules which, on receiving the stimulus it imparts, assumes the power of growth. It is the same among the *Phanerogamia*, when the germ cell is impregnated by the pollen tube. In all these cases it is necessary to remember that the protoplasm is a mass of molecules ; that a spore is another mass of molecules ; that sporules are molecules ; that antherozoids are only molecules with vibratile appendages ; and that the so-called germinal matter of the ovule is also nothing but a mass of molecules. Cell forms are subsequent processes, and once produced may multiply endogenously, by gemmation, or cleavage. All that is here contended for is, that the primary form is *molecular*, and that the force-producing action in it is a *molecular* force.

In animals, as in vegetables, every primary act of generation is brought about by the agency of molecules. The *Protozoa* entirely consist of mere molecular gelatiniform masses, in which no cell wall or central cell exists. And yet such masses have the power of independent motion, and of multiplying by gemmation. Considerable discussion has occurred as to whether, among *Infusoria*, there is a union of sexes or a conjugation similar to what occurs among the *Protophyta;* but in either case it is by molecular fusion that the end is accomplished. In the higher classes of animals, there are male elements, consisting of molecules, generally with, but sometimes destitute of, vibratile filaments ; and female elements, composed of the yelk within the ovum, containing a germinal vesicle or included cell. Both spermatozoid and germinal vesicle, are dissolved in the molecules of the yelk, which then, either wholly or in part, by successive divisions and transformations, constitute a germinal mass out of which the embryo is formed. Here, as in plants, it is necessary to remember that the spermatozoids, the yelk, and the germinal mass, are all composed of molecules, and that these, combining together, form the nuclei, cells, fibres, and membranes, which build up the tissues and organs of the organism. It is not from either the male or the female element, that the embryo is formed. The supporters of an exclusive cell doctrine have endeavoured to shew that there is always a direct descent, either from the wall of the ovum, or from the germinal vesicle as its nucleus. Thus some consider that the vitelline membrane sends in partitions to divide the yelk mechanically. Others have formed the idea that the germinal vesicle bursts, and that its included granules constitute the germs of those cells which subsequently form in the germinal mass. Others, again, suppose that on impregnation, the germinal vesicle divides first, and that the molecules of the yelk are attracted round the two centres so formed. But numerous observations have satisfied me that both spermatozoid and germinal vesicles, are simply dissolved among the molecules of the yelk, from the substance of which, stimulated and modified by the mixture so occasioned, the embryo is formed—a view which has further the merit of explaining what is known of the qualities of both parents observable in the offspring. The truth appears to be, that in an analogous manner to that in which the pigment molecules of the skin are stimulated by the access of light to enter into certain vital combinations with one another, so the molecules of the yelk are stimulated by the access of the spermatozoid, to produce those other vital combinations that result in a new being. The essential action is not so much connected, as has hitherto been supposed, with the cell wall or nucleus, as with the molecular element of the ovum.

With regard to nutrition, food and all assimilable material must be reduced, in the first instance, to the molecular form; while the fluid from which the blood is prepared—namely, chyle—is essentially molecular. Most of the secretions originate in the effusion of a fluid into the gland follicle, which becomes molecular, and gives rise to cell formation. In muscle, the power of contractility is inherently associated with the ultimate molecules of which the fasciculus is composed. And lastly, the grey matter of the sensory ganglia and of the brain, which furnish the conditions necessary for the exercise of sensation, and of even intellect itself, is associated with layers of molecules which are unquestionably active in producing the various modifications of nervous force. These molecules are constant and permanent as an integral part of these tissues, as much as cells or fibres are essential parts of others; and their presence is not transitory, but essential to the functions of the organs to which they belong.

All morbid growths may easily be shewn to originate sometimes in a molecular blastema, at others in pre-existing cells. The coagulated exudation infiltrated into the lung, or on serous membranes, and from which pus and fibre cells originate, are excellent examples of the former, while the hypertrophy of glands and formation of certain cancerous and cancroid growths are good illustrations of the latter. In morbid alterations of texture, also, we shall have abundant opportunities of pointing out that the molecular law of development prevails, and that histogenetic and histolytic processes constitute the numerous alterations of texture constantly brought under the observation of the pathologist.

All these facts point to the conclusion that vital action, so far from being exclusively seated in the cells, is also intimately associated with the elementary molecules of the organism.

This molecular theory of organisation is opposed to the views of those who support an exclusive origin for the tissues in cells alone. The fallacy of such a cell theory will, however, be manifest by considering for a moment what it imposes upon us. Not the fact, which has been long recognised, that cell may be formed within cell, or that proliferation of cells constitutes an important and a common method of cell multiplication; but *that in no other possible way* can a cell or a living particle be produced. It asserts that all embryonic textures in the ovum, all adult tissues during life, and every kind of morbid formation, are to be traced to the cell, and can originate in it alone. In short, parodying the celebrated saying of Harvey, "*omne animal ex ovo*," it has been attempted by Virchow to establish the law of "*omnis cellula e cellulâ*," and to maintain that "the cell is really the ultimate morphological element in which there is any manifestation of life, and that we must not transfer the seat of any real action to any point beyond the cell."* Now, such a doctrine is inconsistent with numerous facts, and we shall see that histologists (including Virchow himself) have been so unsuccessful in tracing all tissues back to cells, that they have universally recognised that cells must originate, in the first instance, from a formless or molecular fluid or material, called by Schwann a *blastema*. Besides, no attempt has been made (even by Virchow) to shew that muscle, nervous matter, the vascular system, and the blood only originate in cells. He himself admits† that this cannot be established, and describes white or areolar fibrous tissue as originating in intercellular substance, without the agency of cells at all.‡ Several tissues are absolutely structureless, such as the sarcolemma, the neurilemma of the nerve tube, the vitelline membrane, the anterior and posterior layers of the cornea, and the capsule of the crystalline lens. They are apparently the result of simple coagulation and the subsequent union of minute molecules such as occurs in the haptogen membrane. The blood of mammals is, for the most part, not cellular but nuclear, and we shall subsequently see that the nuclei in the adult are more probably the result of molecular than of cell formation. The development of bone, and the various forms mineral matter assumes in the integumentary skeletons of many animals, such as the *Holothuria*, *Sinaptæ*, &c., are wholly opposed to this cell theory, the mineral matter being deposited outside the cells, and often assuming the form of spicules, hooks, anchors, &c., which can have no possible reference to cell growth. Then, so far from it being correct, "that we must not transfer the seat of real action to any point beyond the cell," which is another fundamental part of this cell theory, Virchow admits§ that the contractile action of a muscle is seated *in its ultimate granules;* and he adopts* Du Bois-Reymond's theory of electrical action in nerve as being dependent on "a change in the position which *the individual molecules assume to one another.*" If therefore, it cannot be shewn by the chief supporter of this theory, that many important tissues are formed directly from cells, and if it be admitted that the vital actions of these same tissues are inherent in their ultimate molecules—elements in no way connected with, and quite distinct from cells,—what becomes of the formula, "*omnis cellula e cellulâ,*" and of the doctrine that "we must not transfer the seat of real action to any point beyond the cell?"

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* Cellular Pathology, by Chance, p. 3. † Ibid. p. 50. ‡ Ibid. p. 44. § Ibid. p. 54.

On the other hand, the molecular theory of organisation does not appear to me chargeable with any such defects. It is consistent as a whole, and embraces all known facts. As investigations are multiplied, the more it becomes evident that the ultimate vital elements of the tissues are their molecular, and not their cell, constituents. Indeed, it is now agreed by many upholders of a cell theory, that the potential part of the cell is not the wall nor the nucleus, but the contents. Now these contents are for the most part molecular; and if we must have a doctrine of unities, it is evidently more reasonable to adopt a view of simple unities like molecules, than of composite advanced formations like cells. As a whole, the molecular theory appears to me to possess all the attributes of a true theory, and as such it constitutes not only a basis on which the formation of healthy structures may be explained, but is one eminently valuable when applied to morbid formations, and, above all, in assisting us to reach correct modes of treating disease and a true therapeutics.

From what has been said, it will be apparent that it has not been my object, in directing attention to a molecular theory of organisation, to interfere in any way with the well-observed facts on which physiologists have based what has been called the cell theory of growth. True, this last will require modification in so far as unknown processes of growth have been hypothetically ascribed to the direct metamorphosis of cell elements. But a cell, once formed, may produce other cells by buds, by division, or by proliferation, without a new act of generation, in the same manner as many plants and animals do, and this fact comprehends most of the admitted observations, having reference to the cell doctrine. The molecular, therefore, is in no way opposed to a true cell theory of growth, but constitutes a wider generalisation, and a broader basis for its operations. It is not a fortuitous concourse of molecules that can give rise to a plant or animal, but only such a molecular mass as is formed from organic matter and receives appropriate stimuli, to act in certain directions.

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* Cellular Pathology, by Chance, p. 290.

These views, originally put forth by the author in 1855, are supported by a multitude of facts and observations accumulated by histologists in past and present times. Many of them, it is true, employ different expressions in referring to the primitive molecular material from which organisation proceeds: thus, it is the "*organised concrete*" of Haller; the "*solidescible nutritive fluid*" of Wolf; the "*primordial mucous layer*" of Burdach; the "*sarcode of Dujardin; the blastema*" of Schleiden and Schwann; the "*proligerous pellicle*" of Pouchet; the "*germinal matter*" of Beale; the "*protoplasm*" of Remak, Von Mohl, and Kühne; the "*embryo-plastic matter*" of Robin; the "*primordial protogenes*" of Haeckel, &c., &c., all of which terms express essentially the same thing. The researches of Robin, Onimus, and others in France, and the recent investigations of Chauveau* and Burdon Sanderson,† which prove that the active powers of contagia are seated in the molecules (called *Microzymes* by Béchamp), and not in the cells nor fluids of infecting matters, may also be referred to as giving this doctrine unequivocal support.

The molecular theory of organisation must ultimately constitute the basis for the arts of horticulture, agriculture, and medicine. Thus vegetables and animals grow by the juxtaposition of molecules, which are introduced into the economy in a fluid holding in solution the particles of which the different textures consist. These are deposited, and so increase of bulk takes place. Any interruption to this process, or any violent disturbance in their statical, chemical, or dynamical arrangements when formed, is the fruitful cause of disease. If this occurs in nervous matter, it causes mental aberration or pain; if in muscle, spasm or paralysis; if in the blood, alterations in growth, secretion, excretion, &c. In cases of faulty nutrition, it is reasonable to conclude, that if we could add to, or subtract from, the particular molecular elements which are essential to that process, we could accelerate or retard it: and this is within the reach of the medical practitioner. For example, codliver oil in scrofulous and phthisical cases operates, not because of any vague specific virtue it has been supposed to possess, but on account of its power of adding to the molecular constitution of the chyle, and thus favouring the building-up function of the blood and tissues. There can be no doubt that iron, lead, opium, strychnine, and other of our remedial agents, must operate on this or that tissue in virtue of the affinities between them and the ultimate molecules of such textures. Again, the law of successive molecular evolutions and disintegrations, to which I have directed attention, points out that in the chain of processes, each step is dependent on the one that precedes it; and that inasmuch as regards form we cannot go farther back than the molecular form, so a knowledge of it and the manner in which it is produced from fluids holding proximate principles in solution, is not only the first step to an acquaintance with organisation, but is the one which should best inform us how to repair that organisation, when so altered as to constitute disease.

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* Comptes Rendus. Tom. LXVIII. p. 289.

† Twelfth Report of the Medical Officer of the Privy Council. 1870.

THE PHYSICAL AND VITAL PROPERTIES OF THE TISSUES.

The living body possesses certain properties which are either *physical* or *vital*. By the term *property* is understood the mode in which any body manifests itself to our senses. Physical properties are those which the body possesses in common with other masses of matter. Vital properties, on the other hand, are peculiar to living beings. They are called *vital* because they cannot be accounted for or explained by any known physical laws, and are believed to obey only such as operate in living organisms. As our acquaintance with the phenomena manifested in living beings has advanced, many of them, which were at one time supposed to be vital, have been brought into the domain of physics; and it is highly probable that some of those phenomena which are at present denominated vital, because we cannot offer any explanation of them, may ultimately be found also to obey physical laws. For this reason, it is now admitted that a knowledge of physics, as applied to physiology, is of the highest importance ; and it is, therefore, our aim, in what follows, to place before the student a condensed statement of those facts in physics which are illustrated by, and throw light upon, many physiological phenomena.

I. THE PHYSICAL PROPERTIES OF THE TISSUES.

These may be described under the following heads : 1st, General properties, such as gravity, divisibility, porosity, compressibility, and elasticity ; 2d, Molecular properties, including cohesion, adhesion, and affinity ; 3d, Mechanical properties, such as density, weight, the properties of the lever, and the properties of the pulley ; 4th, Hydrostatic and hydrodynamic properties, or the physical properties of the animal fluids ; 5th, Pneumatic properties, or the physical properties of the gases of the body, including a consideration of atmospheric phenomena in relation to physiological action; 6th, Properties relating to heat ; 7th, Properties relating to acoustics ; 8th, Properties relating to optics ; 9th, Properties relating to magnetism ; and 10th, Properties relating to electricity, or animal electricity.

1. GENERAL PROPERTIES.—The general properties of the body are those which it possesses in common with all other bodies ; and they include gravity, divisibility, porosity, compressibility, and elasticity.

a. Gravity.—According to the law of gravity, every body is attracted towards the centre of the earth with a certain determinate force. This force is the resultant of a number of parallel attracting forces, and is equal to, or represents, the weight of the whole body. In whatever position the body may be placed, the resultant always passes through a particular point in it, termed the *centre of gravity.* When one point of a body is fixed, it is said to be *in equilibrium,* if a vertical line drawn from its centre of gravity passes through that fixed point, and if the body is supported at different points, it is in equilibrium when a vertical line drawn through its centre of gravity passes within the geometrical figure formed by joining the lines of support.

In proportion to the smallness of the area of the supporting base, is the difficulty in maintaining equilibrium, and thus it is more difficult to stand upon one leg than upon two. The gymnast, by moving his body from side to side, and skilfully using his balance-pole, maintains his equilibrium upon the tight-rope, by carefully keeping the centre of gravity of his body vertically over the narrow area of the rope. The human body is, upon the whole, symmetrical, and if it were perfectly so, the centre of gravity would be in the medium line ; but the presence of a-symmetrical organs, such as the liver, spleen, and pancreas renders the two halves of the body slightly unequal. When a healthy adult is lying in the horizontal position, the centre of gravity will be found in a plane transversely cut through the last lumbar vertebra. In the new-born infant, it is somewhat higher. But if a man stands erect, a line leading through the centre of gravity of his body will pass through the area included between the soles of the feet, as in Plate IX. fig. 2, where G is the centre of gravity, and G, G^1 the line of gravity. If he has a burden on his back, Plate IX. fig. 2, this burden, having the line of gravity S, S^1, the line of gravity common to both will be g, g^1, passing behind his feet, and the man will be in danger of falling backwards. To avoid this, he bends forwards, as in Plate IX. fig. 1, and thus brings the common centre of gravity, g, g^1, farther forwards, and within the area of the soles of the feet. In the same manner, women advanced in pregnancy bend backwards because the abdomen contains the enlarged uterus enclosing the fœtus and the membranes of the ovum, forming in all a weight of about 11 lbs. The same laws explain the reason why a man stoops forward while he ascends a hill, and extends the trunk and bends backwards while he descends. Again, we observe the influence of gravity in the accidental engorgement of the blood in the veins of the inferior extremities ; in the disappearance of this engorgement on placing the limb in an elevated position ; in the redness and turgescence of the face when the head is kept lower than the trunk ; in the tumefaction which occurs in the back or sides in cases of ascites from *decubitus* ; in the syncope which occurs in a feeble person on sitting or standing up, and which is removed by a horizontal position, &c.

b. Divisibility.—By divisibility is meant that property of matter by virtue of which it may be divided into numerous distinct parts. Every drop of human blood contains many thousands of blood corpuscles, each about the 1.3000th of an inch in diameter. Many of the *Bacteria* observed on the scum which forms, after some hours, on an infusion of hay and straw, are only about 1.150,000th of an inch in diameter (see p. 46). The 1.100th of a grain of strychnia, will kill an adult rabbit ; and as this is diffused through the blood, it is almost impossible to conceive the minuteness of the particles into which it is divided. One drop of vaccine virus, diffused in an ounce of powdered sugar, has communicated cow-pox to an individual, from the smallest particle of the powder coming in contact with the blood. It is highly probable, however, from recent investigations and calculations by Professor Sir William Thomson,* that there is a limit to the divisibility of matter, when we reach ultimate indivisible particles, termed *atoms.*

c. Porosity.—The molecules of matter are not in actual contact. Spaces, or interstices, exist between them, termed *pores.* In 1661, the Florentine academicians proved the existence of pores, even in so dense a body as gold ; and at the building of the Britannia bridge, it was also found that the water used in the powerful hydraulic presses employed to raise the tube, was freely forced through the pores of the thick iron cylinders of the press. These pores are of two kinds, *physical* and *sensible.* Physical pores are very minute, sensible pores are usually apparent, either to the naked eye or to the microscope. All organic bodies are porous, and the pores may be occupied by fluids or gases. Dry hairs, when moistened, increase in diameter, and diminish in length, in consequence of the passage of fluids into the pores.

d. Compressibility.—This is the property in virtue of which the volume of a body is diminished by pressure, inasmuch as its constituent molecules are brought closer together. Gases are more compressible than fluids, fluids than solids, and by regulating the amount of the pressure, matter may exist in either of these three physical conditions. The various tissues are all more or less compressible. A man is shorter at night than he was in the morning, or after a long journey on foot, from the weight of the head and trunk, compressing the intervertebral cartilages.

e. Elasticity.—Elasticity is the property by means of which a body resumes its original form, when the external force which altered that form ceases to act. A ball of ivory, a steel spring, a caoutchouc bag, and a piece of artery, are all highly elastic bodies. All liquids and gases are perfectly elastic, but there is a limit to the elasticity of solids, beyond which they are either incapable of regaining their original size, or they break. The animal body affords numerous examples of elasticity. We find a highly elastic tissue in the *ligamentum nuchæ*, in the *ligamenta subflava*, and in costal cartilage. The coats of the larger arteries are easily extended, and after the removal of the dilating force, they quickly return to their former condition. Many organs perform their functions almost entirely through the agency of elasticity—destroy it, and the function is abolished. For example, in emphysema of the lungs, expiration becomes difficult, and at length impossible, so that death occurs from these organs ceasing to be elastic. Rigidity of the arteries, from deposition in their coats of mineral matter, by which they lose much of their elastic power, is a common cause of apoplexy. The walls will not yield to the mechanical force of the heart ; they give way, and extravasation of blood into important textures is the result.

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* Sir William Thomson. *Nature.* 1870.

2. MOLECULAR PROPERTIES.—A molecule in physics is a hypothetical particle which is made up of an aggregation of smaller hypothetical atoms of matter. Two forces are ever acting upon these molecules, the one force, termed *molecular attraction*, which manifests itself in various ways, and is designated by the terms cohesion, affinity, or adhesion ; the other, *molecular repulsion*, will be referred to afterwards when describing the properties relating to heat.

a. Cohesion is the force which unites two molecules of any body, and it is usually expressed by the weight which suffices to separate these molecules from each other. A thin iron wire, the transverse section of which is about the 3.1000ths of a square inch, will support a weight of 330 lbs. No part of the animal body has so strong a cohesive power as thin iron wire, but by special combinations of textures, the cohesive power of which may vary considerably, those parts of the body which have to sustain a great weight, or be subjected to considerable tension, are constructed of such a strength that their cohesion is far beyond their most ordinary requirements. According to

Valentin,* it would require a weight of 880 lbs., or about seven times the weight of the whole body, to tear the extensor tendons of the foot.

b. Affinity.—This force is usually termed chemical attraction or affinity. It unites the elements into compound bodies. It is a force of intense energy, is most strongly exerted between dissimilar substances, producing a third substance entirely different in properties from either of the components, and under its influence, the elementary bodies, comparatively few in number, arrange themselves into all the various forms of matter found in the three kingdoms of nature.†

c. Adhesion.—This force is exerted between the superficial molecules of bodies in contact. It produces the phenomena of *friction*. When two surfaces of any body are pressed together, the superficial molecules interpenetrate, and there is a loss of molecular force, and development of heat. Friction forms an obstacle to movement, but it favours stability. The movements of the abdominal and thoracic viscera, of the joints and tendons, are all accompanied by friction. A loss of power is the result, but this is reduced to a minimum, by the contiguous surfaces being constantly lubricated with fluids, such as the fluid in the various serous sacs and *bursæ mucosæ*, and the synovia of joints.

Molecular forces are constantly operating in all living textures, and have been previously referred to when speaking of molecular coalescence and disintegration (p. 40).

3. Mechanical Properties.—The tissues possess certain properties which obey the laws of mechanics. These may be considered under the heads of density, weight, the properties of the lever and the properties of the pulley.

a. Density.—By density is meant the quantity of matter contained in a certain volume. Certain tissues of the body are more dense than others. Bone is more dense than muscle, enamel than bone. An organ may be more dense in one part than in another, as, for example, the crystalline lens is more dense in the centre than at the periphery.

b. Weight.—Weight may be of three kinds, absolute, relative, and specific. *Absolute* weight is the pressure exerted by a quiescent body upon the surface on which it rests, and is the result of the action of gravity. A book lying on a table, presses on the table with a certain weight proportional to its mass. *Relative* weight is the ratio of the absolute weight of a body to that of another body arbitrarily chosen. It is determined by means of the balance, and the unit of weight now employed by scientific men, is that of a *gramme*, according to the French metrical system of weights and measures.* *Specific* weight is the ratio of the weight of a certain volume to that of an equal volume of distilled water, at 4°C. In other words, it is *specific gravity.*

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* Valentin, Physiology. Translated by Brinton. London, 1853, p. 20.

† Miller's Elements of Chemistry. Part I. Chemical Physics. London, 1867.

The weight of the human body varies much in different individuals. The following table, prepared from the statistics given by J. W. Danson†, from observations upon 4,800 criminals at all ages, shews the weight of the human body up to 30 years, and, in a parallel column, the average height of the individuals :—

Age.	Weight.						Height.	
	Average.		Maximum.		Minimum.		Average.	
	Stones.	*Pounds.*	*Stones.*	*Pounds.*	*Stones.*	*Pounds.*	*Feet.*	*Inches.*
18	8	10.79	10	13	6	6	5	4.34
19	9	4.11	12	8	7	4	5	4.94
20	9	5.58	12	8	7	13	5	5.11
21	9	5.02	12	0	7	3	5	5.57
22	9	12.41	13	2	7	0	5	6.17
23	10	2.95	12	12	7	12	5	6.17
24	10	2.0	12	12	7	12	5	5.94
25	10	5.65	13	8	8	2	5	6.30
26	10	1.06	13	8	6	12	5	6.28
27	10	4.75	13	10	7	12	5	6.38
28	10	2.62	13	2	7	7	5	6.65
29	10	5.53	13	12	8	4	5	7.02
30	10	1.55	14	1	8	1	5	6.36

According to Valentin‡ the weight of the new-born infant is from 6.62 to 6.84 lbs. The weight increases up to the fortieth year in the male, and the fiftieth in the female ; and both then weigh about twenty times the weight of the new-born infant.

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* For a clear and concise account of the French metrical system, see Hoffman's Lectures on Chemistry. London.

† J. W. Danson. *Statistical Society's Journal,* March 1862.

‡ *Op. Cit.*

The weight of the various organs also varies much in different individuals. The following are averages :—*

Organ.	*Weight.*
Heart,—adult male,	11 oz.
adult female,	9 oz.
Brain,—adult male,	$49\frac{1}{2}$ oz.
adult female,	44 oz.
Spinal cord,	1 oz. to $1\frac{3}{4}$ oz.
Liver,	50 oz. to 60 oz.
Pancreas,	$2\frac{1}{4}$ oz. to $3\frac{1}{2}$ oz.
Spleen,	5 oz. to 7 oz.
Lungs,—adult male,	45 oz.
adult female,	32 oz.
Thyroid,	1 oz. to 2 oz.
Thymus, at birth,	$\frac{1}{2}$ oz.
Kidney,	$4\frac{1}{2}$ oz.
Suprarenal capsules,	2 drachms.
Prostate,	6 drachms.
Testes,	$\frac{3}{4}$ oz. to 1 oz.
Unimpregnated uterus,	7 to 12 drachms.

c. *The properties of the lever.*—A lever is a straight, solid, rigid bar turning on an axis. The axis is the *fulcrum*, and the parts of the bar on each side of the axis are the *arms* of the lever. Levers are of three kinds, according to the position of the fulcrum with reference to the power and the resistance. If the fulcrum be between the power and the resistance, the lever is of the first kind (Pl. VIII. fig. 3) ; if the resistance be between the fulcrum and the power, the lever is of the second kind (Pl. VIII. fig. 5) ; and if the power be between the fulcrum and the resistance, the lever is of the third kind (Pl. VIII. fig. 4). A balance is an example of the first kind of lever ; a wheel-barrow of the second ; and the treadle of a turning lathe of the third. An example in the human body of a lever of the first order is seen on rising on tip-toe, when the ankle is the fulcrum, the *Tendo-Achilles* the power, and the ground the resistance (Pl. VIII. fig. 7). The skull in its movements upon the atlas is also an example of the first order of lever. The second order of lever is exemplified in opening the mouth by the action of the anterior belly of the digastric muscle, which is the power, the temporo-maxillary articulation being the fulcrum, and the resistance the temporal muscle (Pl. VIII. fig. 6). The most striking examples of the third order of lever are to be met with in the animal economy. The limbs of animals are levers of this kind. The weight of the limb is the resistance; a strong muscle, capable of very powerful contractions through very short spaces, attached to the bone near the joint, is the power; and the socket of the bone is the fulcrum. At the shoulder joint, the glenoid cavity of the scapula is the fulcrum, the deltoid inserted into the humerus is the power, and the weight of the upper extremity is the resistance. At the elbow joint, the fulcrum is the articular surface on the lower end of the humerus, the power is the biceps inserted into the tubercle of the radius, and the resistance is the fore arm (Pl. VIII. fig. 8). In each of these cases, a powerful contraction of the muscle, acting through a short space, gives considerable motion to the limb; but there is a loss of muscular force, because the power acts on the short, while the resistance acts on the long, arm of the lever. In levers of the third order, therefore, the power must always be greater than the resistance. For example, the biceps is inserted into the radius at a distance of $2\frac{1}{10}$ inches from the elbow joint, while the centre of the palm of the hand is 13 inches from the same axis. Hence, if, as in Pl. VIII. fig. 8, a weight is placed on the palm of the hand held horizontally, the force, P, exerted by the muscle, is expressed by the ratio :— Power : Weight : : 13 : $2\frac{1}{10}$; or, $P = W \times \frac{130}{21} = 6\ W$ nearly: so that to support a weight of 1 lb. in the hand, a force equal to 6 lb. must be exerted by the muscle.*

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* Quain's Anatomy. 7th edition. London.

d. The properties of the Pulley.—An ordinary simple pulley consists of a rope passed over a wheel. The efficiency of the arrangement depends on the rope, not on the wheel, the latter being introduced for the purpose of diminishing friction and the imperfect flexibility of the rope. The pulley is a mechanical contrivance for applying power in a direction in which it may be exerted to advantage. An example of the application of the pulley in the human body is seen in the case of the tendon of the superior oblique muscle of the eyeball, which passes through a fibro-cartilaginous ring or pulley attached to the *fovea trochlearis* of the frontal bone. It is also seen in the case of the tendon of the *circumflexus palati* which winds round the hamular process of the sphenoid bone.

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* Rev. S. Haughton, M.D., F.R.S., "Natural Philosophy." London. P. 20.

4. HYDROSTATIC AND HYDRODYNAMIC PROPERTIES.—A knowledge of the laws regulating the behaviour of liquids at rest or in motion, is of great importance to the physiologist.

Liquidity.—An essential peculiarity of liquids is the great mobility of their particles. The slightest force displaces the molecules of a liquid. This peculiarity is termed *fluidity* or *liquidity*, and it is owing to this property that a liquid assumes the shape of any vessel into which it may be placed. Liquids have been proved, by direct experiments made by Canton, Perkins, Oersted, and more recently by Colladon and Sturm,* to be compressible to a very minute extent. Under atmospheric pressure water is compressed 0.00005 of its bulk. The same experiments proved that liquids are perfectly elastic. As a rule, the densest liquids are those which yield least to compression.

Pressure of liquids.—When pressure is made upon a liquid at one point, the force propagates itself equally in all directions. This is called *Pascal's principle of equality of pressure.* In accordance with this law, every portion of the sides of a vessel containing fluid is exposed to a pressure, corresponding to the weight of the fluid pressing against it. In the vessel of water ACD, Plate VIII., fig. 9, a particle of the fluid at B is pressed downwards by the column of water AB, and upwards by an equal force, and this pressure is communicated laterally to the particles lying in the horizontal plane BD and BC. Thus every point in the sides of the vessel bears a pressure of the same amount as that which acts on the particles of fluid in the horizontal layer. The lateral pressure of a fluid on any area of the inner surface of the vessel is proportional to the depth of that area below the surface of the fluid. This will be evident on looking at Fig. 10 in Plate VIII. In the vessel EH, the fluid column AC transmits its pressure through the layer CD to D; and the column EF transmits its force to G; the pressure at G must therefore be greater than the pressure at D in the same proportion as EF is greater than AC.† The pressure of a fluid, however, depends not merely on the height of the column, but also on the specific gravity of the fluid. A fluid, the specific gravity of which is four times that of another fluid, will exert a pressure four times as great.

The walls of the arteries are always subjected to a certain amount of pressure or tension. By means of an instrument termed the *hæmadynamometer* or *kymographion*, the principle of which is Pascal's law just described, this pressure or tension, or in other words, the strength of the current of the blood, may be accurately measured. This instrument will be fully described in treating of the Practical Physiology of the circulation. The average amount of pressure in the arteries of the larger mammalia amounts to from 5·9 to 6·3 inches of mercury. (See Circulation.)

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* Colladon and Sturm, *Ann. de Chimie,* II. xxxvi.

† Golding Bird and Brook's Elements of Natural Philosophy, London.

Hydrostatic equilibrium.—Water permitted to flow through a series of tubes from a cistern will always tend to rise to the level of the fluid in the cistern. It will do so independently of the calibre and form of the tubes. Let LU in Fig. 17, Plate VIII., be a common reservoir, having inserted in it the differently shaped tubes A B C D E F, and water be poured into D, it will attain the same elevation in each of the tubes, and it will remain in a state of hydrostatic equilibrium.

Principle of Archimedes.—When a body is floating in a fluid, it displaces a certain amount of liquid, and it is subjected to two forces, its own weight and the resultant of the fluid pressures acting vertically upwards through the centre of gravity of the displaced fluid. It will be upheld by a force equal to the weight of the liquid displaced by the body. This is called the principle of Archimedes. The human body is on the whole lighter than an equal volume of water, and if quiescent floats on the surface.

Specific gravity.—Specific gravity is relative weight, and the standard of comparison is the weight of the same volume of distilled water at 4°C. The specific gravity of the various constituents of the body varies within narrow limits. Of all the animal textures, fat possesses the lowest specific gravity, bones the highest. None of the fluids have the specific gravity of water, because they all contain solid matters dissolved. The fluid of lowest specific gravity found in the body is the aqueous humour of the eye. The following is a list of the specific gravities of the more important solids and fluids, according to Valentin : *

Substance.	Specific gravity.
Water,	1000
Blood,	1060
Urine,	1020

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* Valentin, *Op. Cit.*

Substance.	Specific gravity.
Liquor Amnii, Saliva, Gastric Juice,	1004 to 1020
Bile, Lymph, Milk,	1020 to 1040
Brain,	1009 to 1030
Tendons,	1110
Cartilages,	1100
Fresh Bones,	1200
Muscles,	1020

Capillarity or imbibition.—The physical phenomenon of capillarity, or the rise of fluids in fine tubes, is manifested when a tube or rod having a very small diameter is placed in contact with a liquid. When a glass tube, bent as in fig. 13, Plate VIII., is filled with water, the liquid settles into a position of equilibrium, in which the water at A and B is raised upwards against the sides of the tube, so that the surface is concave. But if the same glass tube is filled with mercury, it is not moistened by the mercury, and the mercury, after coming to equilibrium at A and B (Plate VIII. fig. 12), is depressed against the sides of the glass tube, so that its surface is convex. The smaller the diameter of the tube the more apparent are these phenomena. Similar results are observed when two parallel glass plates are brought sufficiently near each other in a fluid. By means of capillarity, water rises in the pores of wood, sponge, &c., and thus becomes diffused throughout the texture. Tendon, membrane, or cartilage will dry into a solid brittle mass unlike anything which occurs in the body, but plunge them into water, and they imbibe moisture, and again become soft, elastic, and resume their original properties. Keeping the tissues moist by means of imbibition, is of immense importance in the animal economy.

Endosmose.—When two liquids of different densities are separated from each other by a thin membrane or porous partition, a current sets in from each liquid to the other, and these currents continue till the two fluids become of the same density. Over one end of a long glass tube (Plate VIII. fig. 14) tie firmly a piece of membrane (A), such as bladder, and fill the tube with a strong solution of sugar. Then immerse this end of the tube in a vessel of pure water (Plate VIII. fig. 15 C). It will soon be found that the fluid begins rapidly to ascend in the tube, and the surrounding water to acquire a sweet taste. Such an instrument is called an *osmometer*. Two currents have been established, the one termed the *endosmotic current* (ἔνδον, inwards, ὠδμος, impulse), flowing from the water into the syrup, and the other, termed the *exosmotic* (ἔξ, outwards), flowing from the syrup to the water. The sugar solution being much more dense than the surrounding water, more water passes into the syrup than syrup into the water. To produce osmose, it is necessary that the fluids be different but capable of mixing, that the densities be different, and that the septum between them be permeable and more freely wetted by one liquid than the other. The liquid which most freely wets the membrane passes out more rapidly than the other passes in. As a general rule, endosmose takes place towards the denser liquid. If a film of collodion forms the septum, with alcohol on one side of it and water on the other, the alcohol will pass towards the water, because the collodion film is more easily wetted by the alcohol.

The investigations of Graham* have led to the following conclusions: 1. Urea, gum, sugar of milk, gelatin, and other neutral organic substances, exercise almost no osmotic action; 2. Neutral salts, such as sulphate of magnesia, have no special osmotic action; 3. Alkaline solutions produce endosmotic action to a very remarkable extent. When the alkaline solution was placed in the osmometer, a large bulk of water soon entered the osmometer, while only a small portion of the alkaline salt escaped into the water; 4. Dilute acids and solutions of acid salts produced a current in the opposite direction, that is, they passed readily from the osmometer to the surrounding water; 5. In every instance the osmosis seemed to depend on a chemical action on the septum.

Endosmose is seen to take place in the highest degree between gases; and it has been found that the force of diffusion between two gases separated by a septum is inversely as the square roots of their densities. The absorption of fluid by cutaneous surfaces deprived of epidermis, and by mucous and serous membranes are all to be explained by endosmose. A fluid, such as water, having a lower specific gravity than the blood, is rapidly absorbed by the blood vessels of the mucous membrane of the stomach and intestines. The action of certain purgatives, such as solution of the sulphate of magnesia, is also partly explained by endosmotic action. In this instance, the saline solution in the bowel, having a higher specific gravity than the blood, the serum of the blood transudes from the vessel into the bowel. By the researches of Matteucci, it has been shewn that the absorption of fatty matter by the lacteals in the villi of the intestine is also due to osmose. Fatty substances do not moisten the surfaces of membranes, and therefore are not absorbed; but when made into an emulsion by the action of an alkali, they are absorbed readily. (See Chylification.)

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* Graham, *Phil. Trans.* 1854.

Endosmotic action is greatly influenced by the movement of one of the fluids. An arrangement is shewn in Fig. 15, Plate VIII., which illustrates this fact very clearly.[*] Let *b* be a funnel, having attached to it a piece of blood vessel or intestine, immersed in a fluid in the vessel *d*. To the other end of *a* is the bent glass tube *c* dipping into another vessel *e*. If we now allow a fluid continually to flow towards *e*, while the fluid in *d* is at rest, fresh particles of the fluid in *a* are brought into contact at every instant with *d*. Thus the difference in density between fluid in *a* and the fluid in *d* will be kept up for a long time, and the endosmotic action is increased. This experiment shews that the movement of the chyme in the intestines, and of the blood in the vessels, influences osmotic action to a considerable extent.

Dialysis.—According to Graham,[†] all bodies may be referred to one or other of two great classes, which he terms *crystalloids* and *colloids*. The *crystalloids* have a crystalline structure, a sapid taste, form solutions free from viscosity, and have a very strong tendency to diffusion through a porous septum; while the *colloids* (from κόλλη, glue) have a jelly-like consistence, no taste, and diffuse through a porous septum with great difficulty. Colloids, according to Graham, are very liable to change, and colloidal matter is matter in a dynamical condition. All crystalline substances are examples of crystalloids; gum, starch, dextrin, tannin, gelatin, and albumin, &c., are examples of colloids. By the process called *dialysis* (διὰ, asunder, λύσις, separation) these two classes of substances may be separated from each other. A *dialyser* consists of a shallow tray, made by stretching a sheet of parchment paper over one side of a hoop of glass or gutta-percha; place the mixture for experiment in the tray, and then float the apparatus in a vessel of pure water. The crystalloids will gradually diffuse out into the water, while the colloids remain in the dialyser. The importance of the process of osmose and dialysis in a living being must be obvious, especially as regards nutrition, absorption, exhalation, and excretion.

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[*] Valentin, *Op. Cit.* p. 50.

[†] Graham, *Phil. Trans.* 1861–2.

Fluids in motion.—a. Velocity of efflux.—If the vessel *a d* in Plate VIII. fig. 11. be kept constantly filled with water up to the level *e f*, while it is allowed to discharge itself by the orifice *h*, the velocity of efflux is the same as that of a body falling from a height *g h*. The distance *g h* forms the space through which the molecule of water falls. Now, if the level of the liquid be allowed to fall to *l n*, the velocity of efflux will be the same as that of a body falling through the space *n h*. This law was discovered by Torricelli. It is thus the degree of pressure, *g h* or *n h*, which determines the velocity of efflux. This velocity is termed the *theoretical velocity*, as distinguished from the *actual velocity*, which is conditioned by the form of the aperture in the bottom of the vessel, the diameter and course of the tubes through which the fluid is driven, and the amount of resistance offered by bodies which the fluid may meet with on its way. Usually the actual velocity is about 62 per cent. of the theoretical velocity. When a stream of urine is expelled from the bladder by the urethra, it is discharged with less force than that which the muscular walls of the bladder, assisted by the abdominal muscles, impress upon it. The resistance of the atmosphere at the opening of the urethra, and the friction of the fluid against its sides, diminish the velocity of the efflux.

b. Discharge of fluid through tubes.—In the preceding paragraph, we have supposed the fluid to flow directly from a small aperture in the bottom of the vessel. But if a long tube is fitted to the aperture, the friction of the fluid upon the sides of the tube comes into play. M. Poiseuille* has studied the discharge of liquids through small tubes by the simple apparatus seen in Pl. VIII. fig. 16. It consists of a glass bulb, the volume of which, in cubic inches, between the marks M N, has been ascertained. It is furnished with a capillary tube, A B, the length and diameter of which are also known. Water, or the liquid to be experimented on, is now sucked up through the tube A B till it reaches the level M, and the whole apparatus is connected above with a vessel containing compressed air, by means of which a uniform pressure may be obtained. The pressure of the air drives the liquid before it through the tube A B, and the time occupied in the change of level from M to N is noted. The results of these experiments are as follows* :—1. The flow increases directly as the pressure. 2. With tubes of equal diameter, and under equal pressures, the quantities discharged are inversely as the length of the tube. 3. In tubes of equal lengths, but of different diameters, the flow is as the 4th-powers of the diameters : for example, if tubes, one of 0·4 millimetre, another of 0·2 millimetre in diameter, be compared together, the efflux from the larger tube would be sixteen times as great as from the smaller ($4^4 = 256$; $2^4 = 16 \therefore \frac{256}{16} = 16$). The importance of this fact is well illustrated by considering the rate of flow in the capillaries. In the capillary system, the resistance from friction is greatly increased by the narrowing of the tube. Fine capillaries are about 1-11,000th of an inch in diameter. Their transverse section is, therefore, in accordance with the mathematical law that the areas of circles of different sizes are in the proportion of the squares of their diameters, 1,240,000 times smaller than that of a capillary 1-10th of an inch in diameter ($10^2 = 100$, and $11{,}000^2 = 121{,}000{,}000 \therefore \frac{121.000.000}{100} = 1.210.000$). By finding the fourth power of 11,000 ($11{,}000^4 = 14{,}641{,}000{,}000{,}000{,}000$), and dividing it by the fourth power of 10 ($10^4 = 10{,}000$) we arrive at the conclusion that, in similar circumstances, the quantity of fluid flowing out of the small capillary would be reduced to 1-1,464,100,000,000th of that passing out of the larger tube.† The rate of efflux from capillary tubes bears a relation to the density, capillarity, or fluidity of the fluid passing through them. Poiseuille shews it to be highly probable that when various salts are mingled with the serum of the blood, provided they do not coagulate it, retardation or acceleration occurs in the capillaries, according to the nature of the salt employed.

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* Poiseuille, *Ann. de Chimie*, III. xxi. 76

In the human body the interior of the blood-vessels is very smooth, and thus friction is reduced to a minimum. As the blood flows onwards in the arterial system, it passes from larger to smaller blood-vessels, and one might expect that consequently the velocity in the smaller vessels would be greater than in the larger. But the sum of the transverse section of a number of small branches is greater than that of the chief trunk, so that the channel widens in the same direction as that in which this subdivision occurs, and, consequently, the nearer the blood approaches the capillaries, the slower is its flow. But in the venous system, or in the passage of the lymph upwards, or in the passage of an excretion through the ramified ducts of a gland, the velocity of movement is always increasing.

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* Miller. Chemical Physics, *Op. Cit.*

† Valentin, *Op. Cit.*

5. PNEUMATIC PROPERTIES.—Gases are bodies, the molecules of which are in a state of constant repulsion. In a liquid, the forces of cohesion and repulsion exactly counterbalance each other; in a gas, the repulsion predominates. In consequence of this repulsion between its molecules, a gas is highly elastic. Two physical conditions, temperature and pressure, regulate the volume of a gas. The volume of a gas is inversely as the pressure. Heat increases the repulsive force between the molecules, and, consequently, the gas expands,—the rate of expansion being 1-273 of the bulk of the gas for every centigrade degree of temperature. By the combined application of a low temperature and great pressure, many gases have been converted into liquids, and there is reason to believe that, with sufficient cold and pressure, all gases might be compelled to assume the liquid form. When a gas is confined in a limited space, it exerts a pressure equal in intensity at all points, and this pressure will be in proportion to the elastic force of the gas as controlled by temperature and pressure. This property of gases becomes of importance in cases of typhoid fever, in which there is often danger of rupture of the bowel from the accumulation of gas.

The *atmospheric air* is a mechanical mixture of nitrogen and oxygen, in the proportion of four volumes of the former to one volume of the latter. This mixture has weight or pressure, and the amount of this pressure is measured by an instrument termed the *barometer*. It consists of a glass tube A (Pl. VIII. fig. 18), perfectly emptied of air, inverted in a cistern of mercury, BC. The mercury at once rises to D—D, so that the perpendicular column of mercury is supported by the pressure of the atmosphere on the surface of the mercury in the cistern. The *mean height* of the barometric column at noon, at Greenwich, is 29.872 inches, representing a pressure of 14.617 lbs. to the square superficial inch. Thus every square inch on the surface of a man's body, is under a pressure of about 15 lbs.

According to Quetelet, the pressure on the surface of the body of an ordinarily sized man is 224 times the weight of the body. It is evident that such a pressure could not be borne, were it not the fact that this pressure is exerted on the surface of the internal cavities of the body, as well as on the external surface. There are closed cavities of the body, such as the *pleuræ*, the peritoneal cavity of the abdomen, and the synovial cavities of joints, which contain no air, and, in a healthy state, only a very small quantity of fluid, so that the atmospheric pressure maintains the walls of these cavities in close contact with each other, and favours a gliding movement of the one upon the other.

Absorption of Gases.—Solids and liquids absorb, or condense in their pores, a certain definite amount of any gas with which they are brought into contact. Solids, as a rule, absorb less gas than the same volume of liquid. When a liquid is brought into contact with a gas, the gas may either enter into a chemical combination with it, or it may not. In the former case, the amount of absorption will depend on the ordinary laws of chemical action ; in the latter, it will depend on certain conditions of temperature and pressure. Under increased pressure, the amount of gas absorbed is greater. When a mixture of two or more gases is brought into contact with a liquid, with which none of the gases enter into chemical combination, and allowed to remain for a time, a portion of each is absorbed ; but the liquid does not absorb so much of any one gas, as it would have done if that gas alone had been present, and the quantity in that case will depend upon the pressure which each gas exerts upon the liquid.*

These facts are of great importance in the consideration of the function of respiration, and the presence of gases in the blood. Recently Lothar Meyer † has found that the amounts of carbonic acid, oxygen, and nitrogen, absorbed in the blood, vary with the pressure ; but the nitrogen obeys the law of natural pressures, while only a portion of the oxygen and carbonic acid do so. That is to say, a certain amount of oxygen and carbonic acid, remains dissolved in the blood, independent of pressure ; and it is a remarkable fact, that the amount of the oxygen thus retained, is much greater than the absorbed portion. "From these facts, we may draw the interesting conclusion, that the richness or poverty of a given volume of air in oxygen can exert but a very slight influence on the total volume of oxygen contained in the blood, and therefore upon animal life." ‡

Diffusion of Gases.—All gases, even where they do not enter into chemical combination, diffuse themselves through one another, and form a uniform mixture. This phenomenon takes place even though the gases are at perfect rest, and their specific gravities different. The law which governs this diffusion, established by Graham,* is, that the relative diffusibility is inversely as the square roots of the densities. This property of gases, secures the dilution of noxious gases and vapours by pure air, and man is thus protected so far from their injurious effects. Respiration itself depends upon the process of diffusion, a fresh supply of air taking the place of that which had been rendered unfit to support life by the chemical changes which it has undergone.

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* Roscoe, Article "Gases." Watt's Dictionary of Chemistry. Vol. ii., p. 792.

† Lothar Meyer, *Phil. Mag.* (4) xiv. 263.

‡ Roscoe. *Op. Cit.* p. 804.

Transpiration of Gases.—When gases were transmitted through fine tubes by Graham,† in a series of experiments corresponding to those of Poiseuille on liquids (p. 119), he found that the rate of efflux of the gas from the tube, or rate of transpiration, as he termed it, was entirely independent of its rate of diffusion. The rate of transpiration increases directly as the pressure, with tubes of equal diameter; the volume transpired in equal times, is inversely as the length of the tube; and as the temperature rises, the transpiration of equal volumes becomes slower. Of all the gases tried, oxygen has the slowest rate of transpiration. The bearing of these facts on the function of respiration, is not yet evident, but they no doubt affect it more or less.

6. Properties relating to Heat.—The term heat is used to express a peculiar sensation, but it also describes the condition of matter which produces that sensation. Our sensations, however, do not inform us of the actual amount of the heat of any object, but they bear testimony to the fact, that it imparts that sensation to our bodies, or removes it. A body having a certain fixed temperature, may appear to our sense of touch to be hot at one time and cold at another.

What is heat? Two theories have been advanced to answer this question: 1st. The *emission* theory, which states that the molecules of all bodies are surrounded by a subtle fluid, which has the power of passing from one body to another. When this fluid enters our body, we feel warm; when it leaves it, we feel cold. 2d. The *undulatory* theory, which asserts that heat is not a fluid, but a *condition of matter* easily transferable from one portion of a substance to another. This condition of matter is believed to be an oscillation of its particles, and the more rapid and extensive these oscillations, the higher is the temperature. This latter view is also termed the *dynamical theory of heat.* According to it, heat is a *mode of motion,* not a material substance. Count Rumford was the first, in 1798, to advance this theory. In the following year, 1799, Sir Humphrey Davy shewed experimentally that heat could not possibly be matter, as it could be actually created by friction. For many years, this explanation of heat was not generally accepted ; but the investigations of several philosophers, of whom we may mention Carnot, John Thomson, Seguin, and Colding, tended to support it. It was, however, reserved for Mayer of Heilbronn, by theory and calculation, in 1842, and Joule, of Manchester, by direct experiments made in the years 1843, 1844, 1847, and 1849, to settle the question, by determining the *mechanical equivalent of heat.* They shewed that heat could be measured accurately, and that it always represented, and was the result of, a certain amount of work ; and they established the great fact, that heat is simply another form of possible force or *energy.* It is never lost or destroyed ; but it may be resolved into other forms of energy. By the term, mechanical equivalent of heat, is meant that the mechanical force represented by a fall of 772 lbs., through the space of one foot, will produce the quantity of heat capable of increasing the temperature of a pound of water by 1° Fahr.* The dynamical theory is the one generally adopted. For the application of this theory to vital phenomena, see Correlation and Conservation of Force under Vital Properties of the Tissues.

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* Graham, *Phil. Mag.* 1833, vol. ii.

† Graham, *Phil. Trans.* 1846, p. 591; and 1849, p. 349.

Sources of heat.—1. The sun. The amount of heat received by the earth from this source in one year would be sufficient to melt a layer of ice one hundred and five feet thick, spread over the surface of the earth.† 2. The internal heat of the earth, which shews itself in hot springs, volcanoes, &c. 3. Friction of one body upon another. The amount of heat derived from this source alone is immense. 4. Chemical action. More or less heat is always developed during chemical action. Under this head may be classed heat developed by living beings, which is the result, as will be explained more fully hereafter, of chemical changes taking place in the tissues. (See Animal Heat.)

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* For further information on this subject, reference is made to Rumford, *Philosophical Transactions*, 1798 ; Davy, Chemical Philosophy, 1812 ; Mayer, Die Mechanik der Wärme, 1867 ; Tyndall on Heat, 3d ed. ; Bence Jones, Croonian Lectures on Matter and Force ; Helmholtz Lectures, *Med. Times*, 1864 ; Professor Tait, Sketch of Thermo-dynamics, 1868.

† Tyndall, Heat as a Mode of Motion, 3d ed.

Effects of heat.—1. Heat elevates temperature, that is, it not only causes a body to produce the sensation of heat, but it increases its tendency to impart heat to other bodies. 2. Heat causes bodies to expand, and converts solid bodies into liquids, and liquids into gases. 3. Heat produces chemical changes, and it also modifies the magnetic, electrical, and optical properties of bodies.*

Specific heat.—It has been found by numerous experiments that the quantity of heat needed to effect a given change of temperature is different for almost every substance ; and these quantities of heat are termed the *specific heats* of the substances. The standard of comparison is the amount of heat required to raise the temperature of an equal amount of water from 0 to 1°C. For instance, the statement that the specific heat of alcohol is .615, implies that the quantity of heat that would suffice to raise the temperature of any given quantity of alcohol from 0° to 1°C, would raise the temperature of an equal quantity of water only from 0° to 0.615. Bright arterial blood has a specific heat of 1.03, and dark venous blood of .89. Muscle shews a specific heat of .74, and fatty bodies .40 to .45. The gases concerned in respiration have small specific heats. Thus, the specific heat of air is .2374 ; of oxygen, .2175 ; of nitrogen, .2438 ; and of carbonic acid, .2163. The specific heat of the same body is commonly greater in the liquid than in the solid state, and always less in the gaseous than in the liquid state.

Changes produced by heat upon gases, liquids, and solids.—As a general rule, all bodies expand on the application of heat. This is due to molecular repulsion. Gases expand at the rate of 1.273d of their volume for every degree centigrade. Liquids also expand, but there is no general law regulating their expansion, as in gases ; for it is found that not only has almost every liquid a co-efficient of expansion different from that of any other, but the co-efficient of the same substance varies much with changes of temperature. Solids also expand, but they vary much in the rate of expansion.

Fusion.—When a body is heated to a certain point it melts, or assumes the liquid form ; when it cools, it resumes the solid form, or solidifies. The temperature at which these phenomena take place varies much. Sulphurous anhydride (SO_2) melts at 80°, tin at 235°, silver at 1000°, and platinum at 2000°. A liquid cooled slowly, and protected from all mechanical disturbance, will not solidify till it has been cooled 10° or 12° below its ordinary point of solidification. In this way, water may be made to freeze at 15° instead of at 0°.

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* Foster, Article " Heat," in Watt's Dictionary of Chemistry, vol. iii. p. 17.

Vapours.—When a little water is exposed to the air, part of it disappears into the atmosphere in the form of vapour. In the case of water, evaporation takes place at all temperatures. When a liquid evaporates in an enclosed space, the amount of evaporation depends on the nature of the liquid, on the temperature, and on the extent of the space. After the space is filled or saturated with vapour, the vapour, in virtue of its elasticity as a gas, exerts a certain amount of tension upon the surface of the liquid, and prevents further evaporation. But if the vapour itself is now submitted, either to pressure or cold, part of it passes again into the liquid state. If, on the other hand, the pressure on the vapour be diminished, or its temperature raised, more vapour is formed in the same space till saturation is again produced, and the tension of the vapour is greater. Evaporation is more rapid in a dry than in a moist atmosphere. The larger the amount of vapour present in the atmosphere, the smaller will be the quantity of aqueous vapour which rises from an exposed surface, and *vice versa.* Evaporation also goes on more rapidly in a strong breeze or current of air than when the air is still. Hence the frequency of catarrh or "cold," and of pulmonary disorders in those who reside in a climate where cold dry east winds prevail.

Boiling or ebullition.—This phenomenon takes place when heat is applied to the lower part of a mass of liquid, and the tension of the vapour produced at the point where the heat is applied, is greater than the pressure of the atmosphere on the surface of the liquid. Bubbles of gas then escape through the superincumbent liquid.

Latent heat.—This term was first used by those philosophers who held that heat was a material substance. When a liquid is changed by heat into a vapour, a certain amount of heat is absorbed, chained up, or made latent, and conversely, when a vapour returns to the liquid state, the same amount of heat is set free. According to the dynamical theory of heat, when heat disappears, or is made latent, it is not lost, but its equivalent is found in the work done in altering the molecular constitution of the substance. Thus the formation of vapour cools bodies, and the condensation of vapours to liquids causes warmth. The temperature of the body is lowered by evaporation from the skin. The amount of evaporation being in proportion to the external temperature, its effect is to keep the blood at or near a uniform temperature. (See Animal Heat.)

Relation of chemical affinity to heat.—Chemical action being the result of molecular forces, is always accompanied by the appearance or disappearance of heat. A given amount of chemical action produces a given amount of heat, and conversely, the same amount of heat is required to undo the chemical action that has produced it. Numerous experiments have been made to estimate the amount of heat produced by a definite amount of chemical action, and the amount is always expressed as so many *units of heat*, a unit of heat being the amount of heat required to raise 1 gramme of water from 0° to 1°C.

The following table gives the quantities of heat, expressed in *heat units*, evolved in the combustion of various substances in oxygen* :—

Substance.	Product and Formula.	Units of Heat.
Hydrogen, . . .	H_2O	33881
Carbon, . . .	CO_2	7900
Sulphur, . . .	SO_2	2220
Carbonic acid, . . .	CO_2	2403
Ether, ...	$C_4H_{10}O$	9028
Stearic acid, . . .	$C_{18}H_{36}O_2$	9716

From this table it is apparent, that when substances rich in carbon and hydrogen (especially the latter) unite with oxygen, a large amount of heat is evolved, a fact which will be seen to be of great importance when we treat of respiration and animal heat.

Conductivity.—Some bodies conduct heat better than others. Surround a body by a badly conducting substance and it may be kept warm for a long time. If we heat the end of a wire in the flame of a spirit lamp, the other end of the wire speedily becomes so hot that we cannot hold it, because the wire is a good conductor of heat. Platinum is a better conductor than iron, iron than lead, lead than marble, and marble than brick. Gold is the best conductor. All organic substances, such as hair, wool, cotton, straw, are bad conductors. Our clothes themselves are not warm, but they prevent our bodies from losing heat because they are bad conductors.

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* Foster, *Op. Cit.*

Radiant Heat.—Radiant heat is heat transmitted from one body to another, without altering the temperature of the intervening medium. All bodies at all temperatures radiate heat. Radiation takes place in all directions, and if through a homogeneous medium, the rays pass in straight lines. If the rays pass from one medium to another differing in density, they are refracted just as rays of light are. Rays of radiant heat may pass through a vacuum. The chief law governing the intensity of radiant heat is that the intensity is inversely as the square of the distance.

Tyndall's researches upon Radiant Heat.—It is well known that from a luminous object, such as a gas flame, two sets of rays pass out, rays of light and rays of heat. The heat rays are far more numerous than the light rays, and their presence may be shewn by directing them to the blackened surface of a thermo-electric pile. Tyndall found that certain substances allow the heat rays to pass through them while they absorb the light rays. Iodine is opaque to light, but it permits heat to pass through it. Bodies capable of transmitting heat are said to have the property of *diathermancy*, bodies which have the power of stopping radiant heat have that of *athermancy*. There is no connection between diathermancy and transparency. Smoky quartz, for instance, which is nearly opaque, transmits heat well, while a clear crystal of alum absorbs much of it. Tyndall has also found that many gases and vapours absorb heat. Dry air absorbs very little heat, but air containing aqueous vapour absorbs a considerable quantity. Consequently, whenever the air is dry, terrestrial radiation goes on rapidly and produces great cold. Tyndall thus describes the great function of aqueous vapour in the atmosphere * :—" Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing to man. Remove, for a single summer night, the aqueous vapour from the air which overspreads this country, and every plant capable of being destroyed by a freezing temperature would perish. The warmth of our fields and gardens would pour itself unrequitted into space, and the sun would rise upon an island held fast in the iron grip of frost."

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* Tyndall, *Op. Cit.*

7. Properties relating to Acoustics.—Acoustics is the study of sounds, and, under the same term, is sometimes included the study of the vibrations of elastic bodies. Sound is the result of the rapid oscillations of the particles of the air communicated to the organ of hearing. Each particle moves only a slight distance to and fro, and this motion of a number of contiguous particles produce what is termed a *sonorous wave*, which impinges on the *membrana tympani* and causes it to vibrate. This vibration is transmitted to the expansion of the auditory nerve in the inner chambers of the ear; an impression travels along the nerve to the brain, and *we hear.* No sound can pass through a vacuum. A bell rung by clockwork or electricity beneath the receiver of an air-pump, gives forth no sound. The *intensity* of sound is governed by certain laws. It is always inversely as the square of the distance of the body from the ear. The greater the extent of the vibrations of the sonorous bodies, the more intense is the sound. If a long vibrating cord be made to oscillate, the oscillations are perceptible to the eye, and it will be observed that as the oscillations diminish in extent, the sound becomes less intense. The density of the medium in which a sound is produced also affects its intensity. A bell rung in a heavy gas like carbonic acid is much more intense than when it is rung in a light gas like hydrogen. A sound is more intense in a medium at rest than in a medium in motion, and thus sounds are heard better in a calm than in a windy day. The proximity of a sonorous body intensifies sound. The violin is a sounding box, above which vibrating strings produce sounds much more intense than if caused to vibrate in free air. The reason of this is, that the air in the box and the box itself vibrate in unison with the air.

If a wave of sound be confined in a tube having a smooth internal surface, it may be conveyed to great distances without losing its intensity to any sensible degree. The speaking tube extensively used in places of business, and the *stethoscope*, an important instrument in the hands of the physician, are illustrations of the application of this fact in acoustics.

Velocity of sound.—A wave of sound takes a sensible amount of time to travel from one place to another. In ordinary air, at a temperature of 0°C, the velocity of sound is 1090 feet a second, and it augments about 2 feet for every degree centigrate added to its temperature. Sound travels much more slowly than light ; hence we see the lightning flash some time before we hear the thunder. If a discharge of thunder takes place from an elongated cloud, a prolonged thunder roll is heard, which is intensified by the echoes of the clouds. Sound travels in water, as determined experimentally by Collodon and Sturm in 1827, at a velocity of about 4708 feet in a second, or more than four times as rapid as it travels in air. The velocity of sound in wood is about sixteen times as great as in air.

Echoes.—An echo is a repetition of a sound in the air, caused by its reflection from a solid body. The laws regulating the reflection of sound are exactly the same as those of light, and will be referred to when we discuss optical phenomena (p. 135). Sound is reflected by solid surfaces, such as rocks, and walls, and also by clouds. The vibrations of the air are reflected by the ridges and depressions of the external ear, so as to be directed as much as possible into the *meatus.* When sound travels from one medium of a certain density into one of another density, it is partially reflected, and in this way is weakened.

Musical sounds.—Sound may be either *musical* or it may constitute what is termed a *noise.* When a number of sonorous waves impinge upon the *membrana tympani* at regular intervals and sufficiently rapid, a pleasurable sound is experienced, which we call a *musical note.* If the waves come in a series of irregular shocks, a noise is produced. A series of taps produced in any way and with great rapidity, gives rise to a musical note. The taps of a card against the cogs of a rotating wheel, as first shewn by Savart, illustrates this point.* A series of puffs at equal intervals, and rapidly following each other, results in a musical note. This phenomenon is illustrated by an instrument called the syren, first made by Cagniard de la Tour, in which a series of puffs is produced through perforations in a rapidly rotating disk. When the taps or puffs follow each other slowly, a series of shocks on the *membrana tympani* is experienced, and as they increase in rapidity the pitch of the sound rises, and a musical sound is produced. The human ear is so constituted that if the vibrations number less than sixteen a second, we are conscious only of shocks ; and if they exceed 38,000 a second, the pitch becomes so high that the note cannot be heard. The range of the best ear covers about eleven octaves, and the sounds available in music are comprised between the limits of seven octaves. The muscular sound, or *susurrus*, first observed by Wollaston in 1809, which may be heard easily by applying a stethoscope over a vigorously contracting muscle, is produced, according to Collongues and Haughton, by thirty-four vibrations per second. *Tinnitus aurium*, or singing in the ears, resembles a sound produced by 2048 vibrations.

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* Tyndall on Sound. 1867.

A musical tone has three qualities, *pitch*, *intensity*, and *timbre*. Pitch depends on the number of vibrations per second yielded by the body producing the note. Intensity, as has been already explained, depends on the *extent* of the vibrations of the sonorous body. Timbre is that peculiar quality of a note which distinguishes it when sounded on one instrument than when sounded on another. Thus, if the note C on the treble stave be sounded on a pianoforte and a violin, it will have 512 double vibrations a second in both, but the quality of the two will be so obvious that they cannot be confounded.

Physical theory of music.—Musical notes are separated from each other by intervals, and they bear a certain relation to each other. Suppose a note produced by a certain number of vibrations, it will be found that a note which is produced by double that number of vibrations will closely resemble the first one. The higher note will differ from the lower only in pitch, and is said to be the *octave* of it. The series of sounds which connect a given note with its octave is called a *scale*, and the notes are denoted by the letters C, D, E, F, G, A, B. The scale is repeated by taking the octaves of these notes c, d, e, f, g, a, b, and again repeated by another octave c', d', e', f', g', a', b', and so on. It has been found by experiment that if m represent the number of vibrations corresponding to C, the fundamental note of any octave, the other notes will be indicated by the following number of vibrations,—

Names, . .	C,	D,	E,	F,	G,	A,	B,	C,
Intervals, . .	1st	2d	3d	4th	5th	6th	7th	8th
Rates of vibrations,		$\frac{9}{8}m$	$\frac{5}{4}m$	$\frac{4}{3}m$	$\frac{3}{2}m$	$\frac{5}{3}m$	$\frac{15}{8}m$	$2m$.

These eight notes constitute the *natural* or *diatonic* scale. If we multiply these ratios by 24, so as to avoid fractions, we obtain the following whole numbers, which express the relative ratios of the vibrations of the notes of the scale,—

27, 27, 30, 32, 36, 40, 45, 48.

The intervals, or ratios of the times of vibration of each note to the note next below it, are represented as follows,—

C to D,	D to E,	E to F,	F to G,	G to A,	A to B,	B to C.
$\frac{8}{9}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

The intervals $\frac{8}{9}$, $\frac{9}{8}$, and $\frac{10}{9}$ are called *tones*, and exist between C and D, D and E, F and G, G and A, and A and B; the interval $\frac{16}{15}$ is what is termed a *semitone*, and is found between E and F, and B and C. There are thus in the natural scale five tones and two semitones. If C, E, G, are sounded together on the keys of a piano, we have what is termed a *major triad.* This is the *tonic* or first major triad. When G, B, D^2 are sounded, we have the *dominant* or second major triad; and when F, A, C^2 are sounded, we have the *sub-dominant* or third major triad. The number of vibrations of the three notes C E G, G B D^2, and F A C^2 are all in the proportion of 4, 5, 6; and a scale formed in this way of major triads is a *major* scale. In it, the semitones fall between the third and fourth, and seventh and eighth notes. In what is called a *minor scale*, the semitones are between the second and third, and seventh and eighth notes, the sixth and seventh being raised a semitone; but in the descending minor scale the semitones are between the sixth and fifth, and third and second. When a series of notes are separated only by semitones, produced by interpolating other notes, we obtain a *chromatic scale.* The notes so interpolated in the five intervals called tones do not receive special names, but are called the *sharps* and *flats* of the natural notes above or below which they occur. A chromatic scale is seen in Plate VIII. fig. 19*a*.

Harmonics.—When one of the keys of a musical instrument, such as a piano, is touched, the note corresponding to that key is not the only note sounded, but a series of other notes, each of less intensity than the one preceding it, are also produced, which blend with the primary note so as to give the mind the sensation of one sound. Helmholtz calls the first note the *primary tone*, and the other notes the *harmonics of the primary tone;* and he has shewn that the timbre of a note produced on different instruments depends on the different intensities of the harmonics which accompany the primary tone of the sound. The pleasure experienced on sounding two notes, such as C and its octave, depends on the harmonic notes that accompany the primary note. These sounds which please the sense of hearing when played together are called *concords*, and those which do not, are called *discords.* Two notes, differing from each other by an octave, played together, produce a more agreeable sound than any other two notes. The first and fifth notes also produce an agreeable sound.

Compass of the Human Voice.—The compass of the voice varies in individuals. In Plate VIII. fig. 19. is a scale of the human voice, shewing the mean compass of its different varieties of *bass*, *tenor*, *alto*, and *soprano.* The male bass voice begins at the first F and extends to F^3. The tenor begins at C^1 and extends to C^3. The voices of women, boys, and eunuchs begin at F^2 for alto, and usually reach as high as F^4. The soprano, usually sung by women, begins at C^2 and extends as high as C^4. What are termed *barytone* voices are intermediate between bass and tenor, begin at A and extend to F^2. The *mezzo-soprano* is intermediate between alto and soprano. The lowest note of the female voice is, therefore, an octave higher than the lowest of the male voice ; and the highest note of the female voice about an octave higher than the highest of the male. The compass of the male and female voices together include four octaves.

Vibrations of Strings.—When a string is stretched from one point to another and caused to vibrate, the number of vibrations is always inversely as the length of the string ; and the musical note produced varies according to the number of vibrations. But the note is not a simple one, for it is made up of the primary note of the string produced by the primary vibrations, and of a series of partial secondary vibrations which produce the harmonics of the primary note.

Vibrations of Rods.—Rods of wood, of glass, and of steel, being very elastic, readily vibrate ; and the law regulating these vibrations is that the number of vibrations made in a given time by the rods is directly as their thickness, and inversely as the square of their length. The common tuning fork is an example of vibrations of this kind. It is chiefly by the vibrations produced in the *malleus*, *incus*, and *stapes*, the small bones of the *tympanum*, that sound is conveyed to the inner ear.

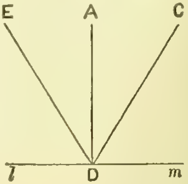
Vibrations of Membranes.—Membranes vibrate if they are stretched, like the skin of a drum. They vibrate either by direct percussion, as in the drum, or they may be set in vibration by the vibrations of the air, as is the case in the vibrations of the *membrana tympani.* The sound of vibrating membranes is acute in proportion as they are smaller, thinner, and more tightly stretched, circumstances which alter the tone of the cardiac sounds.

8. Properties relating to Optics.—Light, by its action on the retina, makes us acquainted with the existence of bodies. It is also a most important agent in working chemical changes.

Theories of Light. — Two theories have been entertained: 1. The *emission theory*, which supposes light to consist of minute particles emitted from luminous bodies. The greatest exponent of this theory was Newton. But as the knowledge of optical phenomena advanced, many facts were discovered which could not be accounted for by the emission theory, and it has accordingly given place to—2. *The undulatory theory*, which supposes that objects are made visible by the vibrations of luminous bodies in an elastic medium, termed *the ether*, which pervades all space. This theory is the one now generally held by natural philosophers. The velocity of light is about 196,000 miles per second.

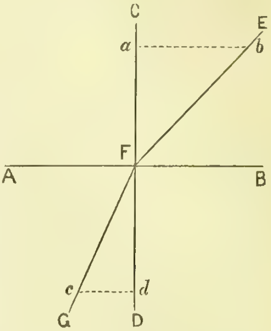
When a body emits light, such as a gas flame, it is said to be *luminous.* When a body transmits light so that objects can be seen through it, like glass, or water, or the cornea, it is *transparent* or *diaphanous.* What is termed a *translucent* body, transmits light, but objects cannot be seen through it. Ground glass or a cornea, rendered hazy by inflammation, are examples of *translucency.* A body is *opaque* when it does not transmit light.

Propagation of Light.—In a homogenous medium, light passes on in a perfectly straight line. If, in its course, it meets with a different medium, it is bent or *refracted;* if it impinges on a body it cannot penetrate, it glances off it, or is *reflected.* Rays of light may either run parallel to each other, or they may separate or diverge from each other, or they may converge so as to meet at one point, termed the *focus.*



Reflection of Light.—When a luminous ray impinges upon a polished surface, it is reflected from it. Let *l m* be a plane reflecting surface, C D, the ray of light falling on it, termed the *incident ray*, A D, a line drawn perpendicular to the surface, and D E the reflected ray. The angle C D A, is called the angle of incidence, and the angle A D E, the angle of reflection. The angle of reflection is always equal to the angle of incidence, and the incident and reflected rays are both in the same plane, which is perpendicular to the reflecting surface. A certain amount of light is, however, lost, as the quantity in the reflected ray is less than in the incident ray. The phenomena of reflection are seen in mirrors. Mirrors may be either plane, convex, concave, spherical, &c. In a *plane* mirror, like what is in ordinary use, the image is formed behind the mirror at a distance equal to that of the reflected body from the mirror ; and in such a mirror the image is of the same size as the object (Plate VIII. fig. 20), When an object is placed before a *concave* mirror, the image is inverted, and is formed in front of the mirror, in its focus, or point to which the reflected rays converge ; and the image is much smaller than the object, the size being inversely in proportion to the concavity of the mirror (Pl. VIII. fig. 22). The image produced by a *convex* mirror is behind the mirror, and is always erect (Plate VIII. fig. 21). The size of the image is to the size of the object, as the distance of the image from the centre of the mirror is to the distance of the object. In approaching the mirror, the image and object approach to equality in size. These various phenomena may be readily seen in the human eye. The anterior surface of the cornea, and the anterior surface of the crystalline lens, are both convex mirrors, and the concavity in the vitreous humour, corresponding to the posterior surface of the lens, or the posterior surface of the lens itself, acts as a concave mirror. Consequently, on holding a candle before the eye, we see three reflections : 1st, an erect image, produced by the anterior surface of the cornea, that moves upward when the candle is moved upwards ; 2d, an erect and smaller image, produced by the anterior surface of the crystalline lens, which also moves upwards when the candle is moved upwards ; and 3d, a small and inverted image, produced by the posterior surface of the lens, or the anterior surface of the vitreous humour, that moves downwards when the candle is moved upwards. A knowledge of these facts, first described by Cramer, enabled Helmholtz, by means of the *ophthalmometer*, to settle the question of the accommodation of the eye to distance. (See Sight.)

Refraction of Light.—When one half of a straight stick is immersed in water, it will appear crooked or bent into an angle at the point where it enters the water. If it were immersed in alcohol, the bend would be greater than in the case of the water. Let A B represent the surface of the refracting medium, such as water, and E G a ray of light passing from a rarer medium, such as the air, through it; E G will be bent at F towards the line C D, perpendicular to the surface of the liquid. The angle E F C is termed the *angle of incidence*, the angle D F G, the *angle of refraction*. If C D had represented a ray of light, it would have passed straight on without refraction, because it is perpendicular to the surface, but when a ray passes into the fluid at an angle, it will always be refracted or bent towards C D. When the ray passes out of a rare into a dense medium, as from air to water, the angle of incidence is greater than the angle of refraction; and when the ray passes out of a dense into a rare medium, as out of water into air, the angle of incidence is less than the angle of refraction. Now draw the lines, *a b* and *c d*. The first, *a b*, is the *sine* of the angle of incidence, the other, *c d*, the *sine* of the angle of refraction; and the refracting power of different bodies is indicated by the ratio these two sines bear to each other, this ratio being termed the *index of refraction*.



The following table shews that bodies vary in their power of refracting light, when it passes from one medium to the other:—

Name.	Sine of the Angle of Incidence is to the sine of Angle of Refraction as,
Water,	1.336 is to 1
Ether,	1.057 is to 1
Alum,	1.457 is to 1
Crown glass,	1.534 is to 1
Plate glass,	1.542 is to 1
Canada balsam,	1.549 is to 1
Ruby,	1.779 is to 1
Diamond,	2.439 is to 1
Cornea,	1.330 is to 1

Lenses.—A lens is a transparent medium which, from the degree and kind of curvature of its surfaces, has the property of causing luminous rays to converge or to diverge. They may be of six kinds: 1. double convex (Pl. VIII. fig. 23, 1); 2. plano-convex (Fig. 23, 2); 3. converging concavo-convex (Fig. 23, 3); 4. double concave (Fig. 23, 1^1); 5. plano-concave (Fig. 23, 2^1); and 6. diverging concavo-convex (Fig. 23, 3^1).

Spherical aberration.—The rays refracted by the margins of the lens are more refracted than those nearer the centre, and consequently the former come to a focus at a point nearer the lens than the latter. This phenomenon is termed the *spherical aberration* of the lens, and as it produces an indistinct image, it is always corrected in perfect optical instruments. How this is done in the case of the compound microscope will be explained in the third part of this work. (See Practical Histology.)

The *focus* of a lens is the point where the refracted rays or their prolongations meet.

Images are formed by lenses in the same manner as they are formed by mirrors. When an image is formed by a convex lens, it is inverted in position relatively to the position of the object, and the size of the image is to that of the size of the object as its distance from the lens is to the distance of the object from the lens. The crystalline lens is a lens of this kind, and the radii of its curvatures are such that it brings the rays of light emitted from a luminous body placed before the eye to a focus upon the retina.

Interference of rays of light.—When two rays of light, proceeding from two radiant points placed very close together, meet one another in such a manner as to counteract or modify each other's action, *interference* is produced. Light, according to the hypothesis generally accepted, consists of undulations or waves in the luminiferous ether. It is quite evident that two waves may meet in such a way as the one will entirely destroy the action of the other. When this is the case, there is darkness by *complete interference.*

Diffraction.—When light passes by the edge of an opaque body, or through a small opening, a number of alternate bright and dark bands or coloured fringes is seen around it. This is the result of diffraction, a modification of the luminous rays in virtue of which they become bent or inflected round the edge of the opaque body, just as a wave of water will turn the angle of a wall or spread itself through a narrow opening.* Diffraction may be seen in the fringes produced by rays passing along the edge of a screen, or the edge of a mirror, or at the side of narrow rectangular openings.

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* Roscoe, Article "Light," Watt's Dict. of Chem., vol iii. p. 601.

Dispersion of light—When a narrow beam of sunlight is passed through a glass prism and received upon a screen, an image called a *spectrum* is produced, shewing a series of colours in the following order: red, orange, yellow, green, blue, indigo, violet. The arrangement is seen in Pl. VIII. fig. 26. Let a pencil of rays, S, be admitted into a dark room through the hole H in the shutter E F, it would be carried in the direction of the dotted lines, and appear as a white spot of light on the wall. But if the prism A B C be placed before the hole, the rays of light will be refracted so as to produce the prismatic spectrum M N. The red rays are less refracted than the orange, the orange than the yellow, the yellow than the green, the green than the blue, the blue than the indigo, and the indigo than the violet. This grand discovery was made by Sir Isaac Newton, and was stated by him as follows:—Solar light may be separated into a number of rays of different colours. To each colour there corresponds a definite degree of *refrangibility*, or degree of refraction; the red rays being the least, the violet rays the most refrangible, and the intermediate colours increasing regularly in refrangibility from the red to the violet. When these colours are reunited, a beam of white light is produced.

Fraunhofer's lines.—In 1802, Wollaston, by viewing through a prism a ray of light admitted through a narrow opening in a shutter, discovered a number of fine dark lines parallel to the edge of the prism, or to the boundary lines of the several colours; and in 1807, Fraunhofer of Munich, without being acquainted with Wollaston's observations, made the same discovery in a spectrum formed by a telescope. These lines, usually called *Fraunhofer's lines*, are mostly perfectly black. They are irregularly distributed through the spectrum. Eight of the most distinct of them are denoted by the first eight letters of the alphabet, beginning from the red of the spectrum. Kirchoff has observed 2000 lines, and has laid down a very elaborate map of the solar spectrum.

Kirchoff[*] has advanced an ingenious theory to account for these lines. When sodium is ignited, a spectrum is produced in which two bright bands correspond with the double line D of the solar spectrum; and if through a flame, coloured by sodium, rays from an oxyhydrogen lime light, or from an electric light, be projected, the continuous spectrum produced by either of these sources of light is interrupted by a black line coinciding with the solar line D. In like manner, the spectra of potassium, copper, &c., may be represented by dark lines, or be, to use the phraseology of Kirchoff, *reversed.* On these facts Kirchoff founds an explanation of the lines. He supposes the luminous atmosphere of the sun contains the vapours of various metals, which vapours absorb some of the rays of light proceeding from the intensely heated liquid nucleus of the sun, so that the lines are only the reversed bright lines which would be visible if the nucleus did not emit rays of light. Practically, these facts have introduced a new era into chemical investigation. By means of what is termed *spectrum analysis*, even new elements have been discovered, and the extensive distribution of many elements has been recognised. It has also been applied to physiological research. The hydrochloric acid solution of the ash of human tissue gives a spectrum, shewing the presence of potassium, sodium, lithium, rubidium, cæsium, and calcium. The spectral phenomena of the blood have already been described (p. 32). Bile and urine also give *spectra*, but not very characteristic.

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[*] Kirchoff. Researches on the Solar Spectrum, and on the Spectra of the Chemical Elements, translated by Roscoe. 1868.

Fluorescence.—If we fill a clear glass bottle with a solution of sulphate of quinine, and carefully examine it, we shall find that when looked at by transmitted light, it is colourless, but when viewed in reflected light it presents a bluish colour. This is due to fluorescence, a phenomenon first explained by Professor Stokes.* He found that light separates itself into three sets of rays: heat rays, colour rays, and a third set of rays which were usually invisible to the human eye. These rays are of a peculiar bluish colour, and come from the part of the spectrum a little beyond the extreme violet (Plate VIII. fig. 26). These blue rays are remarkable for their very powerful chemical action, and immediately affect chloride of silver and other photographic preparations, and they are rendered visible by a solution of sulphate of quinine, because the atoms of this fluid are transformed by them into self-lighting bodies, so that when placed in these rays they emit a peculiar bluish light. An alcoholic solution of chlorophyll, in this way, produces a red light, tincture of turmeric a greenish, a decoction of madder mixed with alum a yellow, and so on. Dr Thudicum has applied to physiological chemistry the method of obtaining fluorescence recommended by Professor Stokes, and by its aid has been able "to identify many substances, and to discover at least five new bodies."*

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* Stokes, *Phil. Trans.* 1852. *Journal Chem. Soc.* 1864.

Chromatic aberration.—A lens may be supposed to be a combination of two prisms. Consequently, light passing through it is decomposed, and as the red rays are less refrangible than the violet, they are brought to a focus farther from the lens than the violet rays. In like manner, each colour of the spectrum has its own focus, and thus, when an object is examined by such a lens, a fringe of colour is seen around it. By combining lenses of substances having different dispersive powers, and so arranged that the dispersive power of the one substance is counteracted by that of the other, the images of objects viewed through such lenses do not appear coloured. When light is thus refracted without decomposition, what is termed *achromatism* is produced, and the lens is an *achromatic lens.* The lenses of the human eye produce an achromatic combination.

Colours of thin plates.—Thin films, or laminæ of all transparent substances, appear coloured with very bright tints, especially by reflection. A drop of oil spread over the surface of water shews all the colours of the spectrum. The thin film of a soap bubble exhibits brilliant irridescent colours, especially at its thinnest part. When a thin layer of air is pressed between two parallel surfaces of glass in strong daylight, there is seen at the point of contact a black spot surrounded by six or seven coloured rings. These are known as *Newton's rings.* All these phenomena are produced by the interference of light, which has been already described.

Colour of fibres and grooved surfaces.—It has been long known that mother of pearl, the scales of many butterflies, the wing-cases of beetles, the feathers of birds, the scales of fishes, and some hairs, such as those of the annelid called the *Aphrodite* or sea mouse, shew beautiful irridescent colours when viewed by reflected light. This appearance is due to the existence of minute grooves upon the surface of these bodies. Sir David

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* Thudicum, Appendix to Tenth Report of Med.-officer of Privy Council. 1867. P. 200.

Brewster,* who investigated this subject in 1833, allowed melted wax, gum arabic, or isinglass, to indurate upon a surface of mother of pearl, and found that the surface of the mould or cast shewed the irridescent colours of the mother of pearl. These were produced by an exact impression having been made on the wax, or other substance, of the grooves on the mother of pearl, the number of which is so great as 3000 in an inch. When plates of steel, gold, silver, lead, tin are covered with fine grooves, they shew the same phenomena. The presence of oil upon the grooved surface increases the number and distinctness of the colours. The same phenomenon is also seen on fragments of glass which have been long exposed to the corroding action of the air or earth. These colours are due to reflection. Experimenting with plates of steel artificially grooved, Sir David Brewster found the following results :—

No. of grooves in square inch.	Tint produced.
312	White.
1000	Yellowish green.
2500	Blue.
3333	Gamboge yellow.
10000	Fine blue.

Colours.—Colours are *simple* or *compound.* Simple colours are those of a pure spectrum ; compound colours are produced by the mixture of two or more of the simple or primary colours. It was once held that there were three primary colours, red, blue, and yellow ; and that all the other colours of the spectrum could be produced by combinations of these. Helmholtz † has, however, shewn that at least five are necessary, red, yellow, green, blue, and violet. Every colour has a *complementary colour*, or rather a number of complementary colours, by uniting with which it produces *white* light.

Polarisation of Light.—When a ray of light falls upon the surface of most transparent bodies, such as water, glass, and certain crystals, it is refracted according to the law of sines (see p. 136) already explained. But many bodies, such as hair, horn, shells, resins, gums, jellies, &c., refract the ray of light, so as to divide it into two different rays, more or less inclined to one another. The separation of the two rays is sometimes very great. This phenomenon is termed *double refraction*, and the body producing it is a *doubly refracting* body. A rhomb of transparent, colourless, Iceland spar, is admirably fitted for shewing double refraction. This will be readily understood by studying Fig. 24 in Plate VIII. Let A X be a prism of Iceland spar, resting on a sheet of white paper, having a black line M N drawn upon it. If we now look in the direction of R *r*, we see that the line M N is double, two lines, M N, *m n*, being distinctly visible. On turning the crystal round, still maintaining the same face on the paper, we see that in one position only, the two lines coincide with each other. This one direction, in which the division of the ray does not take place, a direction parallel to the line which connects the two obtuse angles of the crystal A X, is called the *optic axis*. These phenomena are accounted for by the fact, that the ray of light R *r*, is refracted by the action of the surface into two pencils, *r* O, *r* E, each of which being again refracted by the under surface of the rhomb, at the points E O, will move in the direction E *e*, O *o*. The line *r* O, is called the *ordinary* ray, the index of the refraction being 1.654; the line *r* E, the *extraordinary* ray, the index of refraction 1.483, being less than that of the ordinary ray. These rays are not only equal in intensity, but they possess other properties, which are expressed by saying, they are *polarised*. They are called *rays* of *polarised light*, because they have sides or poles of different properties, and planes passing through them, are called *planes* of *polarisation*. The properties of a polarised ray all relate to changes of intensity or modifications of colour. Light may be polarised in the following ways: —1. By reflection from the surface of a transparent medium, such as a plate of glass. 2. By ordinary refraction. 3. By double refraction. When light is polarised by this latter method, both the ordinary and extraordinary rays are polarised; and it is often convenient to throw one or other of these rays completely out of view. This may be done either by *reflection* or by *absorption*. The apparatus used for throwing out the ray by reflection, is called a *Nichol's prism* (Pl. VIII. fig. 25), which consists of two similar prisms of Iceland spar, cut in a particular manner, and cemented together with Canada balsam. A ray of polarised light may also be absorbed by means of a plate of tourmaline, cut so as to allow the extraordinary ray to pass through polarised, while the ordinary ray is completely absorbed.

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* Sir David Brewster, Optics. *Op. Cit.*

† Helmholtz, *Ann. Chim. Phys.* (3) xxxvi.

When a ray of polarised light is transmitted through plates of doubly refracting bodies, brilliant colours are observed. Certain substances have also the power of rotating the plane of vibrations of a polarised ray of light, so as to produce very beautiful effects. Sometimes the plane of polarisation revolves from left to right (like the hands of a clock), in others, from right to left. Among organic substances which rotate the plane of polarization to the right, may be mentioned, cane sugar, glucose, diabetic sugar, milk sugar, quinidine, narcotin, croton oil, &c.; and to the left, starch, albumin, quinine, strychnine, morphine, &c., &c. This kind of polarisation is called *rotatory polarisation.*

Chemical action of Light.—Many substances undergo chemical changes when exposed either to the light of the sun or to artificial light; the changes thus effected, are said to be chemical action induced by light. An instance of this is seen in the remarkable power plants possess of decomposing, by the aid of sun light, carbonic acid gas into its constituent elements, carbon and oxygen. It has been found, that the violet or most refrangible rays, and those rays beyond the violet, on which depend the phenomena of fluorescence, possess this power to a greater degree than the red rays, which are heat-giving rays.

Theory of the relation between heat and light.—This theory supposes that the particles of all bodies are in a state of constant motion, and the intensity and rapidity of this motion produces in the etherial medium surrounding them more or less rapid undulations which affect our senses. In proportion to the rapidity and intensity of these undulations, our minds experience the sensation of heat alone, or of heat accompanied by light. When a body is heated, molecular movements occur, and it first gives out heat without light; at a certain temperature, the vibrations are so rapid as to produce in our minds, through our organs of vision, the sensation of red light; and at still higher temperatures, the vibrations are still more rapid, and we have the sensations of yellow and blue light. These sensations of red, yellow, and blue light we unite synthetically by an unconscious process, and the sensation of white light is the result.

Phosphorescence.—When the particles of a body vibrate so that they emit light without a perceptible amount of heat, probably owing to slow chemical action, the body is said to be *phosphorescent.* This phenomenon received the name of phosphorescence, because phosphorus, in a state of slow combustion, emits vapours which shine in the dark with a faint blue light ; hence the term has been employed to all bodies shewing a similar luminosity. Some minerals, such as native tricalcic diphosphate, or *phosphorite*, when gently heated, emit light, which soon ceases, and cannot be renewed until the body has been exposed to sunlight. Dead wood, putrid sea fish, various flowers of living plants, such as those of *Calendula officinalis*, and *Papaver orientale*, and *Rhizomorpha subterranea*, a plant found in mines, all exhibit phosphorescence under certain circumstances.* It is also shewn by many living animals, as by the glow-worm (*Lampyris noctiluca*) and fire-fly (*Elater noctilucus*), and also by many small crustacea, medusæ, polypora, and infusoria, which illuminate the sea at night. Phosphorescence may be produced artifically by heat, by the electrical discharge, by mechanical action, and by exposure to the sun's rays.

9. Properties Relating to Magnetism.—The native black oxide of iron (Fe_3O_4), mineral loadstone, possesses at certain parts of its surface, termed *poles*, the property of attracting small pieces of iron. This peculiar property was well known to the Grecian philosophers, and they gave to the ore the name of *magnetes*, from a village near which it was found. Hence the terms *magnet* and *magnetism.*

Magnets.—These are either natural or artificial. They are natural when composed of the ore or mineral just mentioned ; they are artificial when made of iron or steel, to which the magnetic property has been communicated from a natural magnet. When a bar of steel is rubbed along its surface in a constant direction with the pole of a natural magnet, it becomes itself a magnet, attracts iron, and imparts its property in a similar manner to other bars of steel. A bar of steel or soft iron is also converted into a magnet, while a current of electricity is passed along a wire coiled round it.

Direction of a freely suspended magnet.—When a small magnetic needle is hung by a thread attached to its centre of gravity, so that it can move freely in a horizontal plane, it always takes up a particular position, one end pointing towards the north, and the other to the south pole of the earth. The two ends of the bar are accordingly termed the *north* and *south poles* respectively. A magnetic needle also takes up a particular position with reference to the horizon. This position is termed the "dip" of the needle. At the equator, the needle is horizontal; in the northern hemisphere, the north pole of the needle dips, and in the southern hemisphere the south pole dips. The cause of these attitudes of the suspended needle is, that the earth is a great magnet, the northern hemisphere exhibiting southern, and the southern hemisphere northern, magnetic polarity.

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* Balfour's Botany, vol. ii. p 674.

Magnetic attraction and repulsion.—If to a freely suspended magnetic needle another magnet is presented, it will be found that the south pole of the one attracts the north pole of the other, but repels the south, while the north pole attracts a south pole, but repels a north. Hence, the general law is, "*Similar magnetic poles repel, dissimilar poles attract each other.*"

Magnetic induction.—When a piece of unmagnetised iron is attracted by a magnet, it becomes itself a magnet by what is termed *induction.* The north pole of the magnet converts the end of the iron nearest to it into a south pole, and *vice versa.* This explains why a magnet in the form of a horse-shoe is stronger than a bar magnet of the same size. When a horse-shoe magnet attracts a bar of iron, the north pole of the magnet is attached to the south pole of the bar of iron, and the south pole of the magnet to the north pole of the bar of iron. Thus the piece of iron will be held with greater force than it would be by either of them alone.

Constitution of Magnets.—A magnet may be conceived as being made up of a number of hypothetical molecules, each having a north and a south pole, and all the similar poles pointing the same way (Plate VIII. fig. 27). In a row of such molecules, the opposite polarities towards the middle of the series neutralise one another, and thus magnetic action is perceptible only at the poles.

Ampère's theory of Magnetism.—Ampère's theory is that the phenomena of magnetism depend on currents of electricity circulating round the molecules of a magnet, moving parallel to each other, and in the same direction so as to represent a single spiral current. He was able to shew all the phenomena of magnetic action in a helical arrangement of conducting wires.

Electro-magnetic Rotation.—In 1821, Dr Wollaston surmised, and in the same year, Faraday, then assistant in the Royal Institution of London, demonstrated by experiment, that a wire, conducting a current of electricity, could be made to rotate round a magnetic pole, and conversely, that a magnet could be made to rotate round a conducting wire.*

Magnetism and Diamagnetism.—Up to the year 1845, when Faraday made his discovery of the universality of magnetic action, and of diamagnetism, it was supposed that magnetism was peculiar to a small number of bodies. Faraday then found that all bodies are subject to magnetism, but are not all affected by it in the same way. He divided substances into two great classes—the *paramagnetic* and the *diamagnetic.* All paramagnetic (*πάϱα*, by the side) bodies are attracted by either pole of a magnet, and when suspended over the poles of a horse-shoe magnet, point *axially*, that is, in a straight line between them. See Plate VIII. fig. 28, where N S is a powerful electro-magnet, firmly fixed in a wooden support. A B is a thread of silk suspending the substance to be examined. When a current of electricity is passed along the wires C Z, the apparatus becomes powerfully magnetic. The bodies belonging to this class are mostly metallic, viz., iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, and osmium.

The second or diamagnetic (*διὰ*, across) class of bodies includes all organic and inorganic substances which do not belong to the magnetic class. When a magnetic body is suspended over the poles of a powerful horse-shoe magnet (Fig. 28), it places itself *equatorially*, that is, *at right angles* to the straight line joining the two poles, because it is probably *repelled* by the poles. All animal textures and the entire body of a living animal are diamagnetic. Physicists have not yet agreed upon a satisfactory theory of diamagnetism.

10. Properties relating to Electricity.—More than two thousand years ago, a Grecian philosopher, Thales, observed that when amber was rubbed with silk it had the power of attracting certain bodies ; and he ascribed the influence to an inherent soul which, stirred up by friction, went forth and drew the particles to itself.† The Greek word for amber is *ἤλεϰτϱον* ; hence our modern name *electricity*.

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* Faraday. Life and Letters. By Dr Bence Jones. Vol. I. p. 338.

† Ganot's Physics. *Op. Cit.*

Nature of Electricity.—Electricity is a powerful physical force inherent in all bodies, and evolved from them by friction, chemical action, heat, magnetism, vital changes, and by all kinds of motion. Various theories of electricity have been advanced; but three are of chief importance, viz., those of (1) Franklin, (2) Dufay and Symmers, and (3) the dynamical theory.

(1) *Franklin's, or the one fluid theory.*—He supposed that in all bodies there existed a subtle fluid which repelled its own particles. When any body contains its own definite amount of this fluid, it is a *state of equilibrium;* when a body has more than its proper amount of the fluid, it is *positively* electrified; when less, *negatively* electrified.

(2) *Dufay and Symmer's, or the two fluid theory.*—This theory states that there are two fluids, the *positive*, or *vitreous*, and the *negative*, or *resinous.* When they are combined, they neutralise each other, and the body is in its natural condition. When there is excess of positive fluid, the body is *positively* electrified; when there is excess of negative fluid, it is *negatively* electrified. A negative fluid always repels a negative fluid; and a positive repels a positive; but a negative attracts a positive, and a positive a negative. This theory has been generally accepted until recent times.

(3.) *The Dynamical Theory.*—Electricity, according to this theory, like heat and light, is *a mode of motion.* There is an etherial medium filling up the interval of bodies and pervading space, and the phenomena of electricity are due to peculiar vibrations of this medium. One kind of these vibrations may produce heat, another light, and a third kind may constitute the phenomena we include under the term electricity.

Conductors and non-conductors.—Electricity passes easily through or along the surface of some bodies, but other bodies offer resistance to its passage. When electricity passes through or along the surface of a body without much resistance, it is called a *conductor.* When a substance offers resistance to the passage of electricity, it is termed a *non-conductor* or *insulator.* The following is a list of conductors arranged according to their conducting power, the best conductors being placed first: the metals, charcoal, dilute acids, saline solutions, animal fluids, living animals.

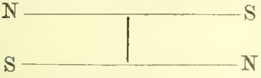
The metals vary greatly in conducting power. The best conductor is silver, next copper, gold, sodium, calcium, potassium, iron, tin, platinum, lead, mercury, bismuth, and the worst conductor of all is tellurium.

As examples of electrical non-conducting substances may be mentioned caoutchouc, porcelain, dry paper, wool, hair, feathers, silk, glass, wax, sulphur, resin, amber, and shellac. Gutta-percha possesses great insulating power.

Induction.—The action of an electrified body on others near it is termed *induction* or *action at a distance.* When a conductor, A, is placed near an electrified body, B, A becomes charged with the opposite kind of electricity to what it had before, and, if moveable, is *attracted* towards B. If both A and B are conductors, and are brought into contact, the moment they do so, the two electricities combine, and both bodies becoming similarly electrified, A and B *repel* each other. Upon these phenomena of attraction and repulsion, are constructed almost all the instruments for ascertaining the nature and intensity of the electricity with which a body is charged. Such instruments are termed *electroscopes.* The ordinary gold leaf electroscope (Pl. VIII. fig. 32) consists of a glass bottle having attached to its neck by gum mastich, a brass tube closed at the top by a thick brass plate. To the brass plate is a wire coated with shellac, and to the lower end of this wire are two strips of gold leaf of about an inch in length. Facing these gold leaflets on the exterior of the bottle, are pieces of tinfoil. When a body positively electrified is brought near such an apparatus, the leaflets at once diverge, often with such force that they are in danger of being torn.

Detection of electrical currents.—Professor Oersted of Copenhagen, in the year 1820, discovered that, when a magnetic needle is suspended or carefully balanced in the magnetic meridian, under or above and parallel to a wire conducting a current of voltaic electricity, the needle immediately tends to place itself at right angles to the wire. This experiment was the origin of *electro-magnetism.* An arrangement is shewn in Pl. VIII. fig. 31 for illustrating this fact. Let N S be a needle freely balanced on W S, and A B a wire conducting a current from C to Z in the direction of the arrows. If N S is placed on the magnetic meridian, and a current of electricity is sent from C to Z, the magnetic needle, N S, will immediately move so as to place itself as near as may be to a right angle to the wire, A B. In the same year, Schweigger, a German philosopher, applied this discovery of the action of a conducting wire on a magnetic needle to the construction of an instrument for shewing the direction and measuring the intensity of voltaic currents. This instrument is termed the *galvanometer*. It consists of a coil of wire, insulated by being covered with silk, in the centre of which is suspended, by a very delicate filament of silk or cobweb, a magnetic needle. Above the coil there is a card graduated into 360 degrees. On passing even a feeble current along the wire, the needle is at once deflected. Nobili greatly improved the galvanometer by introducing the astatic needle.

The astatic needle of Ampère.—As a magnetic needle always points to the north pole of the earth, it is evident that before using the galvanometer as at first constructed, the coil of wire must be placed parallel to the needle that is pointing north and south. To obviate this inconvenience Nobili made use of the astatic needle of Ampère, which consists of two needles instead of one, connected together by a bit of straw or a fine piece of tortoiseshell so that the north pole of the one is over the south pole of the other, and *vice versa*. Such an arrangement constitutes an *astatic system*, and as the one needle neutralises the other, both, when suspended, are liberated from the static action of the earth, and swing freely in any direction. In most galvanometers, however, a small magnet is placed so as to keep the needle parallel with the coil.



The multiplying Galvanometer.—By increasing the number of coils, the galvanometer becomes more sensitive, and indicates, by a deflection of the needle, even the weakest currents. The reason of this is, that the action of the wire above and below the needle tends to move it in the same direction, and thus every additional coil multiplies the electromagnetic action, and produces a greater and greater deflection of the needle. The most delicate galvanometer yet constructed for physiological use, is that of Du Bois-Reymond, the Professor of Physiology in Berlin, in which the wire is about 16,752 feet long, and forms 30,000 coils round the needle. Sir William Thompson, of Glasgow, has devised a galvanometer of less bulk, in which there is a small vertical mirror fixed to a light astatic needle suspended by a short thread. The mirror reflects upon a graduated scale the ray of light from a lamp carefully adjusted before the apparatus, and thus the slightest movements of the needle are apparent. More recently, Sir William has invented a self-recording galvanometer, but it has not yet been used in physiological research. (See Practical Physiology.)

Modes of producing electricity.—These may be classified as follows:—1. by friction (*frictional electricity*); 2. by heat (*thermo-electricity*); 3. by chemical action (*Galvanic* or *Voltaic electricity*); 4. by induction (*Faradic electricity*); and, 5. by living organised structures (*organic electricity*).

1. *Electricity produced by friction.*—The simplest instance of this is the electricity produced by rubbing a glass rod or a stick of sealing-wax with a piece of flannel. Such a rod, when brought near a gold leaf electroscope, immediately causes the strips of gold leaf to diverge. The action of the ordinary electric machine is founded on the excitation of electricity by friction. This mode of producing electricity is not of much service in physiological research.

2. *Electricity produced by heat.*—When two pieces of different metals are soldered together, and heat is applied to the point of junction, an electric current is established, when the point of junction is brought to a temperature different from that of the rest of the circuit. The strongest current of this kind is produced by a circuit of bismuth and antimony. Such a combination of two metals is called a *thermo-electric pair*, and a number of these pairs placed together constitutes a *thermo-electric battery*, *chain*, or *pile*. An apparatus of this kind is termed *Melloni's pile.* Thermo-electric arrangements have been successfully used by Becquerel and Breschet* in the investigation of animal heat. (See Animal Heat.)

3. *Electricity produced by Chemical Action.*—This is the most important of all sources of electricity, and is the basis of the ordinary voltaic battery. When a system of two dissimilar metals is immersed in a fluid, which acts on one of them, a current of electricity is produced, and we have what is called a *galvanic* or *voltaic couple.* The chemical and other phenomena occurring in a voltaic couple, will be readily understood by referring to Plate VIII. fig. 29. In the glass vessel there represented, partially immersed in dilute sulphuric acid, are two metallic plates, the one, Z, being a plate of zinc, the other, C, a plate of copper. When these two plates are not in contact, little or no action takes

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* Becquerel and Breschet, "Memoir sur la chaleur Animale."—*Annales de Chimie et de Physique,* tome lix. p. 113. 1835.

place, except the formation of a few bubbles of gas on the zinc; but the moment they are allowed to rest against each other, as shewn in the figure, the surface of the copper becomes coated with minute bubbles, which increase in size, and eventually escape into the air. The whole of the liquid in the neighbourhood of the copper soon assumes a state of effervescence, while that around the zinc is free from disturbance. The copper is not acted on chemically, but the zinc is being dissolved. The zinc plate decomposes the film of water on its surfaces ; oxide of zinc (ZnO) is formed, which is rapidly dissolved by the sulphuric acid, forming zinc sulphate ($ZnSO_4$), thus leaving a clean surface of zinc for another film of water, and so on. The other element of water, the hydrogen, passes over to the copper plate, and appears there in the form of the bubbles just described. But the chemical action or force which has divided water into its elements, becomes another form of force, called *electrical force.* A current of electricity has been set up ; starting from the zinc plate, it passes to the copper, and proceeds up the copper to the zinc plate again, as indicated by the arrows in the figure.

The metal most attacked by the liquid in a voltaic couple, is called the *positive*, the other the *negative* metal. In the arrangement just described, the zinc is the positive, and the copper the negative, elements. The part of the metal immersed in the fluid, is termed the *plate*, and the part out of the fluid is the *pole* or *electrode.* As the current always travels in the fluid from the positive plate, where there is the greatest chemical action, to the negative plate, where the action is the least, the positive *pole*, which is out of the fluid, is connected with the *negative plate*, and *vice versa.* Instead of the term pole, the word *electrode* was used by Faraday, and he expressed the emitting or positive electrode, by prefixing the syllable *an*, and the receiving or negative, by prefixing the syllable *cath.* So that, according to this nomenclature, the upper end of the positive element is the *anelectrode* ('ανὰ, up ; ἤλεκτρον, electricity ; ὀδὸς, a way), and the upper end of the negative element, the *cathelectrode* (κατὰ, down ; ἤλεκτρον ; ὀδὸς).

The following is a list of metals arranged according to their electrical behaviour, the electro-positive being placed at one end, the electro-negative at the other. Hence, if any two of these are placed in contact in dilute acid, the current in the connecting wire, out of the fluid, proceeds from the one lower in the list, to the one higher :—zinc, silver, tin, gold, iron, platinum, copper. In the fluid, the current passes from the one higher in the list to the one lower.

Volta's Pile.—This apparatus, invented by Volta, consists of plates of copper and zinc of equal size, arranged, along with pieces of thick flannel, in the following order :—1st. A plate of copper ; 2d. A plate of zinc ; 3d. A piece of flannel moistened with dilute acid, or a strong solution of common salt ; then a plate of copper, then zinc, then flannel, and so on, until a pile is formed. Such an arrangement will yield a large quantity of electricity of low tension. It is never used for physiological research.

Voltaic Batteries.—Voltaic *couples* or *elements* may be united together to form a *battery* in two ways. When all the positives are united on one side, and all the negatives on the other, a battery is made which is capable of generating a large amount of electricity, but electricity having a low tension, or, in other words, a weak power of overcoming resistance. If, on the other hand, it be desirable to give to the current of electricity evolved from any battery a high tension, then the positive pole of one couple must be united with the negative of the next, and so on through the entire series employed. In arranging a series of couples to form a battery of high tension electricity, care should be taken to use batteries whose negative elements are of equal size, as the absolute power of any galvanic arrangement, *cœteris paribus*, depends on the area of the surface of the negative element.

Various batteries or couples are useful in physiological research, but the following are the most important,—

1. *Daniel's Battery.*—This consists of a porcelain or copper vessel containing a saturated solution of sulphate of copper ($ZnSO_4$). Inside the cylinder, is a thin porous vessel of earthen ware, containing a strip or roll of amalgamated zinc immersed in a solution of salt ($NaCl$) or dilute sulphuric acid (7 of H_2O to 1 of H_2SO_4). The action of this kind of battery is constant, because the chemical decomposition which takes place produces a continual deposition of metallic copper, whereby its surface is always kept pure. It also gives a current of considerable intensity. The negative pole in this battery is connected with the zinc (positive plate), and the positive pole with the copper (negative plate), and the current travels, in the fluid, from the

zinc to the copper, and out of the liquid, from the copper to the zinc.

2. *Bunsen's Battery.*—Each element consists of a bar or roll of compact charcoal or coke immersed in a porous earthenware vessel containing strong nitric acid (HNO_3). Round this is a hollow cylinder of amalgamated zinc immersed in dilute sulphuric acid (1 H_2SO_4 to 7 of H_2O), to which is fixed a strip of copper. The upper part of the bar of carbon is fitted with a binding screw serving to connect it with the zinc of the next couple. The positive pole proceeds from the carbon (negative plate), and the negative from the zinc (positive plate). The current travels in the fluid from the zinc to the carbon, and out of the fluid from the carbon to the zinc. This is a most energetic battery.

3. *Grove's Battery.*—In this battery the positive plate consists of a large surface of amalgamated zinc immersed in dilute sulphuric acid (1 of H_2SO_4 to 10 of H_2O), and the negative plate consists of a small strip of a platinum immersed in strong nitric acid (HNO_3). Each zinc plate is coiled round a porous earthenware vessel containing the platinum. The positive pole in this case proceeds from the platinum (negative plate), and the negative pole from the zinc (positive plate). In the fluid, the current travels from the zinc to the platinum, and out of the fluid from the platinum to the zinc. This battery is powerful, but not very constant, and after it has been in action for an hour, copious red fumes of the lower oxides of nitrogen are given off, which render it disagreeable.

4. *Smee's battery.*—This convenient form of battery consists of a sheet of platinum covered with finely divided platinum, or of a plate of platinised silver placed between two plates of amalgamated zinc. There is only one liquid required, dilute sulphuric acid (1 of H_2SO_4 to 7 of H_2O). The negative pole in this couple proceeds from the zinc (positive plate), and the positive pole from the platinum (negative plate). The current therefore travels in the liquid from the zinc to the platinum, and out of the fluid from the platinum to the zinc. The convenience of having to use only one acid (H_2SO_4) in this form of battery is very great, and it gives a tolerably constant current, which, however, unfortunately tends to become weaker and weaker, in consequence of the destruction of the zinc plate.

Electrical forceps, made of coils of zinc and copper moistened with acetic acid, are of great service in physiological experiments.

Another form of battery has lately been introduced. It consists (Plate VIII. fig. 30*a*) of a glass bottle containing a strip of zinc (positive plate) having on each side of it a thin slip of carbon (negative plate) immersed in a saturated solution of bichromate of potash ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) in the proportion of twelve parts of the former to one part of the latter. This is an energetic battery, constant for a few hours, and when not in use, action may conveniently be stopped by drawing out the zinc plate.

Physiological action of the galvanic current.—When the electrodes of a powerful battery are held in the two hands, a strong shock is felt, which is more violent in proportion to the number of couples used. The shock of a single couple is not felt in the hands, but if the terminals are applied to the lips or the mucous membrane of the mouth, or the tongue, a burning sensation and peculiar taste are perceived. When the terminals of a strong battery are applied to the body of an animal recently killed, such as a frog or rabbit, the muscles powerfully contract. In 1819, Dr Ure* experimented on the body of a man who had been hanged, with a like result. The electric current in a healthy individual produces two sensible effects, pain and muscular contractions. When applied to a nerve, it excites the nervous force which, by propagating itself to muscles, produces in them contraction, and by transmitting an influence to the cerebrum produces the sensation of pain. But the muscular contractions, and the painful sensations, are produced only at the moment of opening and closing the current.

Thermal and luminous effects of the galvanic current.—When a strong current is transmitted along a metallic wire, the wire becomes heated, and incandescent if short and thin. This may be readily demonstrated by connecting the two terminals of a powerful battery by a thin piece of platinum wire. In a few minutes, the wire becomes red-hot. A useful application of this fact is seen in the surgical appliance called the electro-cautery, by means of which the surgeon may readily remove polypi without hæmorrhage. When the electrodes of a voltaic battery are brought into contact, a brilliant spark is observed. When a large number of cells are used, and the two wires terminate in pencils of charcoal, a magnificent electric light is obtained. Davy made the first experiment of the electric light in 1801, by means of a battery of 2000 plates, each four inches square.* The electric light has similar properties to solar light.

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* Ure. *Ann. de Chim. et de Phys.* tom. xiv. p. 367.

Chemical effects of the galvanic current.—When an electrical current is passed through water, the latter is decomposed into its two constituent gases, oxygen and hydrogen. This process is called electrolysis (ἤλεκτρον, electricity; λύσις, disintegration). In electrolytic decompositions, one of the elements goes to the positive pole, the other to the negative. The bodies separated at the positive pole, are called *electro-negative* elements; those separated at the negative pole, are called *electro-positive* elements. The same body may be electro-negative or electro-positive. For example, sulphur is electro-negative to hydrogen but electro-positive to oxygen. When the terminals of a battery are dipped into living blood, a clot of fibrin soon collects around the positive pole and bubbles of oxygen arise from the negative pole. This action suggested to surgeons the operation of galvano-puncture, first proposed by M. Prevaz† in 1833, by which the fibrin is coagulated within an aneurismal sac.

4. *Electricity produced by induction.*—Electricity produced by induction, or by action at a distance, is called *Faradic electricity*, in honour of its discoverer, Faraday, who first investigated this form of electricity in 1832. The method of producing this form of electricity will be readily understood by referring to figure in Plate VIII. fig. 30.‡ Let A and B be two wooden pillars firmly fixed in a strong piece of wood. In the top of each of these pillars are two binding screws, by means of which the bent wires, C D and E F, may be attached, one below the other, and about half an inch apart. The galvanometer G is connected with the two inner screws, E F, and one of the outer binding screws, D, with the negative pole of the battery H. There are now two distinct circuits. The one, E G F, includes the galvanometer G, the other consists of the battery A and the wire C D. This last circuit is not yet complete, for the wire C is not connected with the positive pole of the battery. Place the galvanometer so that the needle will be parallel with the wire E F. If the battery circuit be now completed by simply *touching* the positive pole

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* Ganot's Physics, *Op. Cit.*

† Prevaz, *Comptes Rendus*, tom. xxi. p. 992.

‡ Intensity Coils. Dyer. London. 1866.

with the wire from the binding screw C, the needle of the galvanometer will be at once deflected.

This deflection of the needle is caused by a current of electricity passing along the circuit E G F, and as this circuit has no connection with the battery circuit C D H, the current in E G F was *induced* by the current passing in C D H. A current in the galvanometer circuit has been set up by the current in the battery circuit. But if we now *fix* the wire C to the binding screw on the positive pole of the battery, the needle at once returns to its original position, and is quiescent. Separate the wire, and the needle will be again deflected by an induced current, but this time in the opposite direction. The induced current in the galvanometer circuit E G F is, therefore, produced only at the moment of opening and closing the battery circuit C D H. When the battery circuit is closed, a current is produced in the galvanometer circuit in an opposite direction to that in the battery circuit; but when the battery circuit is opened, the current in the galvanometer circuit is in the same direction as that in the battery circuit.

When two coils of wire are used instead of a single wire, as in the experiment just described, a very powerful current is induced in the one at the moment of opening and closing the electrical current in the other. The coil through which the current passes from the battery is termed the *primary coil* (E D H), the coil in which the current is induced, has received the name of the *secondary* coil (E G F). Induced currents are also formed when a primary coil traversed by a current is approached to, or removed from, a secondary one. When the latter is brought near the former, a current is induced in the first in an opposite direction to that of the second; but when a secondary coil is removed from a primary, a current is induced in the secondary in the same direction as that in the primary.

Induced currents may also be obtained by the action of magnets. This kind of electricity is sometimes called *Magneto-electricity*. A current of electricity passed round a bar of soft iron converts it into a magnet, a fact first observed in 1837 by Sturgeon; in like manner, when a magnet is thrust into a coil of soft iron wire, a current of electricity is induced in the coil (Faraday).

The phenomena of induction has given rise to the construction of instruments capable of producing a series of induced currents by rapidly breaking and forming the circuit in a primary coil of wire. These instruments are termed *Ruhmkorff's coil*, *induction coils*, *magneto-electric machines*, &c. A description of these, and of their use in physiological investigation will be given under Practical Physiology.

Variety of currents.—By a *continuous* current is meant a uniform flow of electricity proceeding in a stream from any number of galvanic elements; by an *interrupted* current, one that is broken or interrupted, and then re-formed; and by an *induced* current, a current obtained by an induction apparatus in the manner already described. The physiological properties of each will be referred to under Practical Physiology.

5. *Electricity produced by living organised structures* (ORGANIC ELECTRICITY).—Organised beings, as masses of mere matter, are subject to the laws which determine electrical equilibrium and electrical disturbance. But the physiological changes which occur in the tissues of a plant or animal cause electrical disturbance, and thus give rise to currents. The investigation of these phenomena has received the name of *electro-physiology*, a department of science which, in late years, from the unremitting labours of the German school of physiologists, has made remarkable advances. It may be subdivided into (1) electricity in plants and vegetable tissues (Vegetable Electricity); (2) electricity in animals and in the animal tissues (Animal Electricity).

1. *Vegetable electricity in plants.*—(VEGETABLE ELECTRICITY.) —No definite results have been obtained as to electrical phenomena in plants. Buff[*] has shewn that the roots and central parts of plants are negative to the humid surface of the leaves, flowers, fruit, and young branches; but this condition is probably due to ordinary chemical reactions, and not dependent on vital causes.

2. *Electricity in animals and in the animal tissues.*—(ANIMAL ELECTRICITY.)—This includes a description of electrical phenomena in certain fishes, and in the animal tissues such as muscle, nerve, &c.

ELECTRICAL FISHES.

Certain fishes have special organs for the development of electricity, by means of which they have the power of communicating a shock to other animals, a power they use either for self-defence or for paralysing their prey. The most remarkable of these fishes are :—

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[*] Buff, *Ann. Chim. Phys.* [3] xli. 198.

1. *The Torpedo.*—This fish, a species of ray, termed by naturalists, *Torpedo Galvani*, after the celebrated Bologna professor, is a native of the Mediterranean. It is sometimes found in the Atlantic, rarely in the North Sea. Its powers of giving benumbing shocks was recognised by fishermen before the days of Aristotle, who carefully describes them. J. Walsh* was the first, in 1773, to shew experimentally that these shocks of the torpedo were essentially electrical. The electric organs, two in number, are large, flat, kidney-shaped bodies, placed on each side of the head and gills. The organ is composed of a mass of hexagonal prisms, placed vertically between the dorsal and abdominal integument, and each prism is divided by a series of delicate membranous plates or diaphragms attached by their angles to the aponeurotic sheaths separating the prisms. The plates are separated from each other by a jelly-like albuminous fluid. In each electric organ there are from 400 to 1000 prisms, and it has been estimated that there are about 2000 plates in each prism. This powerful electric battery, thus divided into compartments, is richly supplied with large nerves. These are (1) a large branch from the trigeminal, and (2) four branches from the vagus,† which spring from a large trunk on each side of the fore part of the medulla-oblongata. According to Paccini,‡ the nerves enter the laminæ at their points of attachment to the prisms, and are distributed to their under surface, and in the fluid between that surface and the next lamina. They ramify here in a very vascular nucleated tissue. The upper or dorsal surface of the diaphragm is negative, while the under surface, on which the nerves are distributed, is positive. Each prism is thus analogous to a voltaic pile. In the torpedo the piles are vertical, and the plates horizontal.

2. The *Gymnotus electricus* is an eel-like fish common in the lakes and rivers of South America, especially in Guiana. It possesses four electric organs, two on each side, stretching from the pectoral fins to near the end of the tail. The proportional size of the electric organs to the body is much

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* Walsh. *Phil. Transactions* for 1773.

† Owen, Anatomy of Vertebrates. Vol. i. p. 350-2.

‡ Paccini, Sulla struttura intima dell'organo elettrico del Gymnoto. 1852.

greater in the gymnotus than in the torpedo, the viscera of the animal occuping only a small portion of the anterior part of the body. Each electric organ consists of a series of horizontal membranes or plates arranged in the longitudinal axis of the body nearly parallel to each other. The organ thus resembles a series of galvanic troughs. Each trough is divided by thin vertical laminæ or diaphragms. Each lamina is not simple, as in the torpedo, but, according to Paccini,* it consists of two layers separated by a fluid. The posterior layer is a delicate fibrous structure, and in it alone the nerves ramify. It is the positive element of the battery. The anterior is composed of vascular nucleated tissue, and it is the negative element. The fluid between the two layers of the laminæ differs in character from that in the interspace between the posterior layer and the anterior of the next laminæ, but both fluids are of an albuminous character. The electric battery of a gymnotus, therefore, does not resemble a voltaic pile, with one liquid, but a voltaic battery with two liquids. In the gymnotus, the batteries are horizontal and the plates vertical, the opposite arrangement to that described in the torpedo. The electric organs are richly supplied by the abdominal branches of the spinal nerves, and it is remarkable that they receive no branches from the trigeminal and vagus which supply those of the torpedo.†

3. The *Malapterurus electricus*, Raasch, or thunder-fish of the Arabs, is a native of the Nile, Niger, and other African rivers. The electric organ forms a layer beneath the skin enveloping the whole body with the exception of the head and fins. An insulating layer of fat separates it from the subjacent muscles. The laminæ are traversed by numerous very delicate decussating membranes which divide it into lozenge-shaped cells filled with an albuminous fluid. A large nerve trunk from the commencement of the cord supplies the organ. This is distributed to the abdominal or posterior surface of electrical laminæ, forms a conoidal expansion, and then pierces the centre of the plate, distributing its branches to the thoracic or anterior surface, which is the positive one.‡

4. In addition to these, the *Mormyrus longipinnis*, a fish allied to the pike family, found in the Nile; the *Rhinobatus electricus*, a

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* Paccini, *Op. Cit.*

† Owen, *Op. Cit.*

‡ Max Schultze Zur Kenntniss der Electric. Org. I. Malapterurus, &c. Halle. 1858, s. 14, Taf. i. figs. 1, 2, 3.

ray from Brazillian waters ; the *Tetraodon electricus*, a species of globe-fish inhabiting the Nile ; the *Gymnarchus electricus*, an eel also found in the Nile ; and, the *Trichiurus electricus*, a ribbon-like fish found in the Indian Ocean, are said to possess electrical properties, but not to the extent manifested by the three fishes we have more particularly described. In the common skate, *Raia batis*, there is an organ, first described by Dr Stark in 1844, and afterwards by Robin,[*] which structurally resembles a voltaic pile, but its electro-motor power has never been tested.[†]

General properties of electric fishes.—The electricity generated by these fishes has considerable tension, and is capable of developing the electric spark, of magnetising steel, of decomposing iodide of potassium, and of affecting a galvanometer.[‡] In order to receive a shock, an animal must be in communication with the electric fish at two points, so as to complete the circuit, but the circuit may be completed by the earth. According to Matteucci and Savi,[§] an insulated frog's leg does not contract when the extremity of the nerve attached to it is brought into contact with a torpedo, but the instant a second point of contact is made, powerful contraction ensues. Matteucci also found that while the electric organ was in operation no current traversed the nerves. According to Bilharz,[‖] the nerves are always distributed to the positive side of the electrical plate, a law which anatomical research has fully confirmed. Thus in the *torpedo* the electric current passes from the belly to the back ; in the *gymnotus* it passes from the tail to the head, and the most powerful shock is experienced on grasping the head with the right hand and the tail with the left. As the hands are approximated, the shock becomes weaker. In the *malapterurus* the current flows from the head to the tail. The gymnotus transmits a more powerful shock than the torpedo, and Humboldt[¶] states that so powerful an animal as the horse may be killed by a full grown gymnotus.

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[*] Robin. Robin's *Journal de l'Anatomie.* September 1865.

[†] John Goodsir, "Anatomical Memoirs," vol. ii. p. 295.—Max Schultze, *Reicherts' Archiv.*, 1858.

[‡] Faraday, "Experimental Researches in Electricity," Ser. xv. Du Bois-Reymond.—*Monatsb. des Berlin akad.* 1861. P. 1105.

Matteucci and Savi, "Traité des Phénomènes Eléctro-Physiologiques." 1860.

[‖] Bilhartz. Uber der elektr. Organ der Zitterwelses, &c. Leipsig. 1857.

[¶] Humboldt and Bonpland, "Voyage Zoologique." 1811.

The phenomena manifested by electric fishes are of great interest, because they afford an instance of the relation existing between vital and physical forces. That the organs can develope electricity to a considerable amount only when provided with a proper nervous supply, is proved by the fact that when the nerves are divided no shock is transmitted, but on irritating the distal end of the nerve, the electric discharge is at once felt. Matteucci,* however, states that when a fragment of the electric organ of a torpedo was brought into connection with a galvanometer, the needle was deflected to an angle of from twenty to thirty degrees, indicating that, for a time, the electric organ retains a portion of its activity even after all nervous and vascular connection had been severed. The nerve influence, transmitted from the nervous centres of the animal, probably excites, in some way or other, nutritive changes in particular portions of the battery, electrical disturbance is thus occasioned, and a current passes through the structure. This is produced, according to Du-Bois Reymond, by the same polar action as exists in muscles. As the battery in all electrical fishes is imperfectly insulated, being surrounded by water—a good conducting medium—a large quantity of electricity is lost by diffusion, but so much electricity is evolved that the animal can afford to lose a proportion of it. When, as a result of irritation, a torpedo sends a shock to the body of an animal, the mechanism of the act is that of a reflex or diastaltic action (see Reflex Action) ; and it is confirmatory of this view, that such a poison as strychnia, which excites the reflex motor centres, causes the electric organs to emit a quick succession of involuntary electric discharges, a fact observed by Matteucci and Savi. But the action is also under the control of the will of the animal. On transmitting several powerful shocks the electric organ is rapidly exhausted, and the animal requires an interval of repose and nourishment to recover the loss of nervous energy it has sustained.

ELECTRICITY IN THE ANIMAL TISSUES.

The electrical phenomena manifested by living muscle and nerve have already been briefly referred to (pp. 82 and 97), and the methods of demonstrating these successfully will be fully explained in treating of Practical Physiology. As this subject is of great physiological interest, it will be instructive to trace briefly its rise in the end of the last century, and its progress since that time.

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* Matteucci. *Proceed. Royal Society,* x. 567.

The discovery of animal electricity dates from 1786. It is said that Madame Galvani, on preparing some frogs for culinary purposes, observed that the apparently dead animals became convulsed when brought into the neighbourhood of an electrical machine in action. Her husband, who was Professor of Anatomy and Physiology in Bologna, had his attention directed to these phenomena, and found that the convulsions occurred at the instant a spark was emitted from the conductor, provided some metallic substance was in contact with the nerve of the frog. He then tried the same experiment with lightning, and in the autumn of the same year he endeavoured to discover the action of atmospheric electricity on the prepared legs of a frog when the sky was stormless. On the 20th of September he suspended these frogs to the iron trellis-work surrounding the roof of his house, by means of copper hooks, and saw, when they were blown about by the wind, that convulsions were caused whenever they came in contact with the iron. This observation convinced him that an electrical machine was not required, the same effect being produced on the contact of dissimilar metals (Pl. VIII. fig. 33). He at length concluded that the convulsions were due to inherent electricity, that is, electricity seated in, and originating from, the animal tissues.

Galvani published an account of his experiments in 1791. At this time the existence of a "nervous fluid," a something which, if not life itself, was considered inseparable from it, was keenly debated by the learned, and contended for by the animists. Galvani's discovery, therefore, riveted the attention of ths scientific world—electricity took the place of the nervous fluid, and the entire source of life, as well as the origin of the bodily and mental functions, were now ascribed to the existence of a new principle, which, from the name of its discoverer, was called *Galvanism*.

Among the many distinguished men whose attention was attracted towards Galvani's discovery, the most remarkable was Alexander Volta. He was a physicist and professor of Natural Philosophy in the University of Pavia. At first he entered fully into the views of his countryman, and repeated his experiments. But in his hands, galvanism, instead of taking a physiological and medical, took a physical direction. Finding that muscular contractions in a frog could be produced only by the contact of dissimilar metals, he at length dissented from Galvani's theory of animal electricity. Trying by the same means to produce muscular contractions in the human body, he failed. But on placing a metal above and below the tongue, he detected a peculiar taste at the instant of contact. This experiment had been previously recorded by Sulzer, and laid aside only as curious, but in the hands of Volta it became the groundwork of chemical, or what has been called *Voltaic*, electricity. In opposition to Galvani, therefore, he put forth the opinion that the muscular contractions in the frog had nothing to do with animal, but were caused by a very feeble *artificial*, electricity, which was produced by the application of heterogeneous metals to the limbs of the animals.

In reply to this attack, Galvani pointed out that the contractions might be occasioned by one metal, but Volta then shewed that the two extremities or surfaces of one piece of metal might be in different states of tension, and therefore capable of exciting electricity. Galvani then used mercury alone, to which this objection could not apply, and dipping the muscles into one part of a trough filled with it, and the nerves into another, he thus succeeded in causing contractions. But Volta, by a new series of experiments, demonstrated that mercury was always altering under the action of the air, and that in conjunction with moisture, it could produce electricity independent of an animal. It now became necessary for Galvani to shew that contractions could be obtained without any metal at all, and, aided by his nephew Aldini, he succeeded in doing so, and, as he thought, in for ever silencing his formidable opponent. In fact he discovered that on dissecting out the crural nerve, but leaving one end in connection with the leg, and bringing this nerve in contact with the muscles externally, the latter were thrown into distinct contractions. He also caused the limb to contract by simply bringing the nerve in contact with the muscle of another animal insulated from the limb.

His theory of animal electricity now was, that it was produced in the nervous system, and especially in the cerebrum. The internal substance of nerves he considered to have great conducting powers, but their oily surfaces prevented dispersion through the body, and allowed its accumulation in the muscles. These last he compared to a Leyden jar, the outer surface being negative, the internal, positive. The nerve was analogous to the conductor of the jar. When the nerve connects the inner with the outer surface there is a discharge of electricity, causing irritation and contraction of the muscles.

Volta at first endeavoured to meet these facts by the supposition of a mechanical stimulation of the nerves, but at length shewed, that if not caused by metals, it was necessary that there should be dissimilar fluids and tissues which were capable of exciting electricity. It was admitted even by Galvani's followers that it was essential to the success of the experiment that the muscle with which the nerve was in contact, should be moistened with blood or some thick fluid, and if by any accident the limb remained motionless, it was only necessary, in order to induce muscular contractions, that the parts to be brought in contact, should be moistened with saliva, brine, mucus, &c., or still better, with soapy water, and best of all, with a strongly acid or alkaline fluid.

Galvani, in several letters to Spallanzani, endeavoured to weaken the force of these arguments, as did Humboldt, who shewed that contractions resulted when the circuit consisted only of nerve and muscle, without the interposition of blood, mucus, &c. (Pl. VIII. fig. 24). But about this time, 1798, Galvani fell ill, and died on the 4th of December of that year. Volta's experiments, on the other hand, were continued with unabated energy, and towards the end of 1799, he discovered the Voltaic battery, whereby his opinions, and the production of electricity by the contact of metals and a fluid, was completely proved. This great victory, which Galvani, by his death, escaped the mortification of experiencing, notwithstanding the support of Humboldt, Aldini, Pfaff, and a few others, overthrew the idea of an animal electricity for the space of twenty-eight years. During this period, indeed, its existence was generally regarded with incredulity ; and the term, *animal magnetism*, adopted by impostors, only tended to bring it still more into contempt. Volta died in 1826, and it is curious that only a year afterwards Nobili again revived animal electricity, by demonstrating the existence of an electrical current in the frog. In the interval of twenty-eight years, Voltaic electricity made the most wonderful progress. In the hands of Sir Humphrey Davy it led to the most brilliant discoveries in chemistry, and its subsequent applications to the production of motor power in various ways, and to communication between distant parts of the earth, constitute the wonders of physical science in the present age.

In 1820, Oersted, a Danish philosopher, discovered electro-magnetism. He shewed, as has been already explained (p. 148), that when a continuous galvanic current passes along a wire, placed above or below, and parallel to a magnetic needle, the latter is immediately deflected. This led Ampère to construct the astatic needle, as previously described (p. 149), and in turn, enabled Nobili to construct a galvanometer,* which he rendered exquisitely sensitive by various improvements. He prepared a frog after the method of Galvani, and having introduced its two legs into two glasses of salt water, he united the two vessels by filaments of moist cotton,—the frog's muscles at once contracted; removing the cotton, he connected the two glasses by means of the galvanometer circuit, and he observed a deviation of from 10° to 30°, shewing that *an electrical current was passing from the feet to the head of the animal.* By introducing several frogs into the circuit, he increased the strength of the current. The galvanometer of Nobili enabled physiologists to demonstrate that Galvani and Volta were both right and both wrong. Galvani was right in maintaining the existence of an inherent animal electricity, whilst he was wrong in supposing that the contact of two metals with the tissues was a proof of this. Volta, again, was right in maintaining that galvanism could be produced independently of animals, but wrong in denying that electrical currents existed in them. By the astatic needle, as Du Bois-Reymond happily remarks, metallic electricity was enabled to atone for the wrong she had done to her more tender twin sister in their earlier years.

Whilst Nobili, by his construction of a galvanometer, was of such essential service, he was led into an error, viz., that the deflection of the needle was due to thermo-electricity. It was ten years later, in 1837, that Professor Matteucci, of Pisa,† shewed, that to obtain a deviation of the galvanometer needle, it was not necessary to prepare the frog according to Galvani's method. On connecting any two parts of its body, as, for example, the head and legs, by means of the galvanometer, he at once obtained a deviation. In 1841, he advanced the following law :—"The interior of a muscle, placed in connection with any part whatever of the same animal, such as nerve, surface of muscle, skin, &c., produces a current which goes in the animal from the muscular part to that which is not so."* In this paper, he first described his *muscular pile*, consisting of about twenty frogs' thighs, roughly cut across, and arranged, as seen in Plate VIII. fig. 35. By connecting the stump of the knee with one wire leading to the galvanometer, and the section of the femur with the other, the needle was at once deflected so as to indicate a current passing upwards in the pile from the knee to the thigh. He considered this to be a current different from the frog current of Nobili, and he held that the frog had two currents, (1.) The muscular current (Nobili's) common to all animals ; and (2.) The special current, evolved by the muscular pile, peculiar to the frog.

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* *Ann. de chim. et de Phys.*, 1828. Nobili.

† Matteucci. Essai sur les phénomènes électriques, &c. 1840. Traité des phénomenes électro-physiologiques des animaux 1844.

In 1841, Professor Emil Du Bois-Reymond, of Berlin, repeated Matteucci's experiments, and further investigated the subject with the aid of the most delicate galvanometers, and other ingenious apparatus, constructed by himself. He at length elucidated the law of *the muscular current* as at present understood. This law may be shortly expressed as follows :—"*Any point of the natural or artificial longitudinal section of the muscle is positive in relation to any point of the natural or artificial transverse section.*"† By "longitudinal section," is meant the surface formed by the side of the muscle, or by the sides of the muscular fibres, when these are separated from each other ; and by "transverse section," is meant a surface formed by the base of the fibres. Both transverse and longitudinal sections may be natural or artificial. This muscular current may be found in the muscles of all animals, and there is, acccording to Du Bois-Reymond, no current peculiar to the frog, as Matteucci supposed. From this period a new impulse was given to experimental physiology by the aid of modern instruments of precision.

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* Matteucci, *Comptes-Rendus,* tom. xiii., p. 540.

† Du Bois-Reymond. Untersuchungen über thierische Elektricität. Berlin. 1848.

Theoretical Explanations of the Muscular Current.—Du Bois-Reymond supposes that a muscular fibre is composed of electrical molecules, which he calls *peripolar molecules*, each molecule having an equatorial belt, manifesting positive electricity, placed between two polar regions occupied by negative electricity. (See Pl. VIII. fig. 36). When a transverse section of muscle is made, the negative poles of the component molecules will be laid bare, and thus the section will shew negative electricity, and as the equatorial belts of positive electricity are directed towards the longitudinal surface, that surface will shew positive electricity. Du Bois-Reymond has, indeed, constructed an apparatus which illustrates his hypothesis of the electro-motor constituents of a muscle. This consists of a number of small cylinders of copper (negative element), having two small strips of zinc (positive element) soldered to their outer surface, facing each other on opposite sides. These are fastened in rows, by their ends, to a board provided with a handle on its upper surface. Such a combination as this, when immersed in a fluid, has produced a current corresponding to the muscular current, going from the longitudinal to the transverse section.

Dr C. B. Radcliffe,* of London, has advanced the hypothesis, that in a muscular fibre two sets of electrical molecules exist, the one set in which positive electricity is external and negative internal, arranged round the outside of the fibre ; the other set of molecules in which the negative electricity is external and positive internal, being placed in the core of the fibre (Pl. VIII. fig. 37). Thus the longitudinal surface will be positive, because it is formed of molecules, the external surfaces of which are positive; and the transverse surface will be negative, because molecules will be laid bare, the external surfaces of which are negative.

Par-electronomy.—This term (*παράνομος*, *contrary to law*), is applied by Du Bois-Reymond, to describe the electrical condition of the layer of muscle next a tendon, or of muscle which has been subjected to great cold. When a muscle so prepared, that instead of making an artificial transverse section, the tendon is employed as a natural transverse section, is introduced into the galvanometer circuit, there is a deflection of the needle so as to indicate either a very weak current in the usual direction from the longitudinal to the transverse section, or a current in the reverse direction. To explain this, Du Bois-Reymond modified his theory of *peripolar* molecules, and conjectures that muscle is made of *dipolar* molecules, with their positive poles in contact, and their negative poles away from each other. Now, if the layer next the tendon consists of one set of such molecules, they must have their positive poles next the tendinous surface.

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* Radcliffe, Lectures on Epilepsy, Pain, Paralysis, &c. 1864.

Electrical state of a muscle during contraction.—When a portion of muscle is properly placed in the galvanometer circuit, there is a deflection of the needle to an extent proportionate to the strength of the current. If, after allowing the needle to come to rest, the muscle be now thrown into a state of contraction by any irritant, such as strychnine, common salt, or an interrupted current, the needle at once returns in the direction of zero, and after oscillating for a few seconds, comes to rest near to but seldom at that point. The muscular current has been diminished. Occasionally the needle will pass to the other or negative side of zero. When this takes place, the phenomenon is termed *negative variation*, and is the result of another counter current produced at the electrodes, and which acts when the ordinary muscular current is weakened or destroyed by contraction.*

When the two hands are introduced into the circuit of the galvanometer in the manner to be described in treating of Practical Physiology, we find no deflection of the needle till the muscles of one of the arms are caused to contract, when there is a slight deflection of the needle indicating an upward current in that arm. On contracting both arms we get irregular deflections. This current, developed during contraction, is the negative variation of the muscular current of the limb. While the muscles of both arms are inactive, their currents being both feebly positive, are in equilibrium, and there is no deflection of the needle; but on the muscles of one arm only being contracted, it becomes negative, and gives rise to a slight deflection of the needle.

Matteucci's secondary contraction.—When two frogs' limbs, prepared according to Galvani's method, one having the sciatic nerve dissected out, are placed near each other on an insulating plate, it will be found that if the nerve of the one limb be laid on the muscles of the other, and a shock is given to the latter, the muscles of the other limb will contract. In like manner, if two nerves, each connected with a limb, are laid on each other, an electrical shock to one limb will at once induce contraction in the other. This secondary contraction is the result of the negative variation of the ordinary muscular current produced.

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* Du Bois-Reymond, *Op. Cit.*

Cutaneous currents.—Du Bois-Reymond* also found on applying a piece of the skin of a frog to the cushions of the galvanometer, that there was a distinct current flowing from the external to the internal surface, which was easily destroyed by the application of irritants, for example, saline solutions.

Nerve current.—Du Bois-Reymond discovered that when a portion of nerve is introduced into the galvanometer circuit, so that the longitudinal surface is in contact with one electrode, and the transverse with the other, there is a distinct but comparatively slight deflection of the needle indicating a current running from the longitudinal (positive) to the transverse (negative) surfaces.

Effects of electricity on nerves. — An interrupted galvanic current transmitted along a nerve weakens, and if too long continued, destroys the nerve current and the excitability of the nerve. But if a constant galvanic stream be sent along a portion of nerve, it is thrown into a peculiar condition, called by Du Bois-Reymond the *electrotonic state* (ἠλέκτρον, electricity ; τόνος, tension. This term was first used by Faraday to describe the peculiar molecular condition of a wire traversed by a current of electricity. If the constant stream passes in the natural direction of the nerve current, this electrotonic state is augmented ; if in the contrary direction, it is diminished. While a portion of nerve is in an electrotonic state, it may be shewn experimentally, as will be fully described under the head of Practical Physiology, that its physiological action has undergone certain modifications. For the sake of clearness, we shall subdivide this physiological action of the nerve as follows,—1. its electric power, or power of evolving electricity ; 2. its conductibility, or power of conducting the influence of impressions ; and, 3. its excitability, that is, the property of nerve in virtue of which it is capable of receiving impressions and generating an influence.

While a portion of nerve is traversed by a constant current, it is divided by a neutral point, situated between the two poles, into two areas. The area in the neighbourhood of the positive pole is termed the anelectrotonic area (ἀνω, upwards; ἠλεκτρον, electricity; and τόνος, tension) while that in the neighbourhood of the negative pole is termed the cathelectrotonic area (κατὰ, downwards; ἤλεκτρον, electricity; and τονος, tension). The anelectrotonic area extends for some distance outside the positive pole, and the cathelectrotonic area for some distance outside the negative pole. The position of the neutral point, or point of indifference, that is the point where the nerve is neither in a cathelectrotonic, nor in an anelectrotonic state, and the extent of the cathelectrotonic and anelectrotonic areas is determined by the strength of the electrical current transmitted through the nerve. With a current of *medium* strength, the neutral point is exactly midway between the two poles, and the two areas are equal in extent, as will be seen in the following diagram :—

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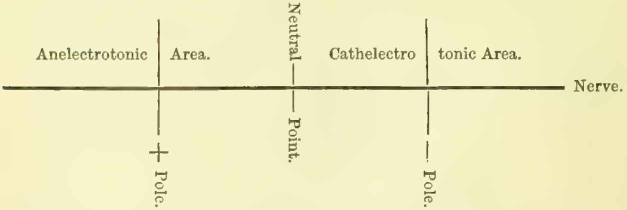
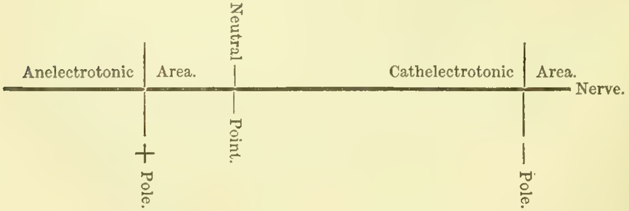
* Du Bois-Reymond, *Op. Cit.*

Medium Current.

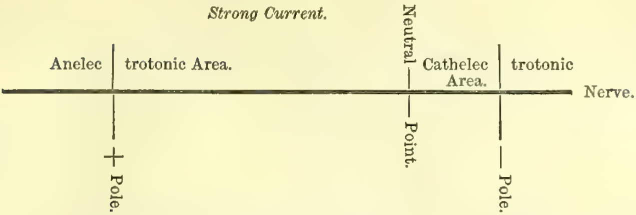


With a weak current, the neutral point is nearer to the positive than to the negative pole, and the greater portion of the nerve is in a cathelectrotonic condition. Thus :

Weak Current.



With a strong current, the neutral point is nearer to the negative than to the positive pole, and the greater portion of the nerve is in an anelectrotonic condition. Thus :



Of course intermediate strengths of the current will cause intermediate positions of the neutral point.

Pflüger discovered that under these circumstances the excitability and conductibility of the nerve are diminished in the neighbourhood of the *positive* pole, while its electric power is increased ; but the excitability and conductibility of the nerve are increased in the neighbourhood of the *negative* pole, while its electric power is diminished. In other words, when a portion of nerve is in the anelectrotonic condition, its power of receiving impressions is diminished, it does not conduct nervous force so rapidly, but it evolves more electricity than it would do in the normal state. The reverse is the case when a portion of nerve is in the cathelectrotonic state. It is then more excitable, conducts nervous force more rapidly, but its power of evolving electricity is diminished.

These results may be impressed on the memory by the aid of the following table :—

STATE OF NERVE.	FUNCTION OF NERVE.		
	Electric Power.	Conductibility.	Excitability.
Anelectrotonus	Increased.	Diminished.	Diminished.
Cathelectrotonus	Diminished.	Increased.	Increased.

Pflüger's Law of Contraction.—By the law of contraction is meant all the actions which a muscle exbibits on opening or closing a current, varying in strength and direction, passing through its nerve. Many of the earliest experimenters in electro-physiology were struck by the fact, often observed, that a *feeble* current of electricity acting on a nerve will cause contraction in a muscle when a *strong* current fails to do so. It was also observed that while a constant current was flowing through a portion of nerve attached to a muscle, the muscle contracted *only on opening and closing the current*, and not during the passage of the current. But the muscle sometimes contracted, sometimes it did not. Numerous experiments, made by Du Bois-Reymond, Eckhard, Pfaff, Ritter, Nobili, Pflüger, Schiff, Wundt, Cl. Bernard, Fick, and C. Bland Radcliffe, have shewn that the phenomenon of the contraction of the muscle is influenced, *first*, by the direction, and, *second*, by the strength of the current sent through the nerve. In the description of these phenomena, physiologists have made use of certain terms it is necessary to explain. When the current is transmitted from the muscle in the direction of the spinal cord, the current is called an *upward* and *inward* or *centripetal* current ; when from the cord in the direction of the muscle, it is called a *downward* and *outward* or *centrifugal* current. When the current was derived from only one of Grove's cells, the strength of the current is described as *weak;* when from two or three of Grove's cells, as *medium ;* and when from five or six of Grove's cells, as *strong*. In these experiments, small elements or cells are employed, and an instrument, termed a rheocord, for further regulating the strength of the current, is introduced into the circuit. (See Practical Physiology.) By means of an instrument, termed Du Bois-Reymond's key, the current may be opened or closed at pleasure. It is broken or interrupted when the key is *opened*, and is again allowed to pass onwards when the key is *closed*.

The following table shews the results of Pflüger's experiments,* and is sometimes termed *Pflüger's law of contraction*, though it is really a table of facts, to explain which Pflüger has discovered a law called *Pflüger's law of stimulation* :—

Current Strength.	Upward Current.	Downward Current.
Weak . .	*Clos.* Contraction.	*Clos.* Rest.
	Open. Rest.	*Open.* Strong contraction.
Medium . .	*Clos.* Strong contraction.	*Clos.* Strong contraction.
	Open, Strong contraction.	*Open.* Strong contraction.
Strong . .	*Clos.* Rest.	*Clos.* Strong contraction.
	Open. Very strong contraction.	*Clos.* Rest, or feeble contraction.

On beginning with an exceedingly feeble upward current, neither opening nor closing gives rise to contraction ; but, by increasing the strength of the current gradually, we invariably get contraction first on closing, but opening has no effect. By gradually strengthening the current, we at length reach a point when there is contraction both on closing and opening. By and bye, a certain maximum is reached, the closing contraction becomes weaker, and finally disappears when the current becomes strong. Similar results are to be got with a downward current, except that contraction with a weak current first appears, according to many experimenters, on opening and not on closing, and that there is contraction on closing, and none, or a very feeble contraction, on opening a strong current. Pflüger, however, found that with a weak downward current he obtained contraction on closing and rest on opening, a result in accordance with the theory of stimulation he has offered.

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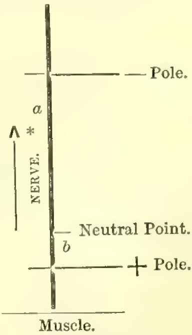
* Pflüger. Electrotonus.

Pflüger's law of stimulation.—To explain these phenomena, Pflüger has propounded the following law :—"*A given piece of nerve is stimulated only by the appearance of cathelectrotonus, and the disappearance of anelectrotonus, but the disappearance of cathelectrotonus and the appearance of anelectrotonus has no effect.*" In other words, when a current is closed, the nerve is stimulated by the passage of the nerve near the negative pole from a normal into a cathelectrotonic state ; but when a current is opened, the nerve is stimulated by the passage of the nerve near the positive pole from an anelectrotonic into a normal state.

Pflüger's theory of stimulation affords a satisfactory explanation of the results given in the table already quoted, and it also explains why a feeble current causes contraction more strongly than a powerful one. This will be evident if we apply it to the individual instances by the aid of the following diagrams :—

1*st. Feeble upward current.*—*Closed*, Contraction ; *Opened*, Rest. Here the point of indifference is near the positive pole, and consequently the cathelectrotonic area is extensive. When the current is closed, the nerve is stimulated by the establishment of cathelectrotonus in the portion, *a*, in which the excitability of the nerve is increased, and a contraction of the muscle is the result. On the other hand, on opening the current, a small portion of the nerve in the neighbourhood of the positive pole, *b*, passes from the anelectrotonic into the normal state, and the nerve is stimulated, but the excitability of the



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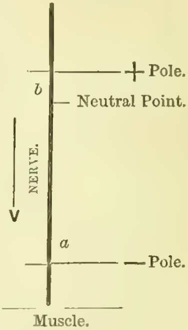
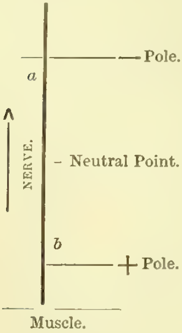
* The arrow ———> indicates the direction of the current.

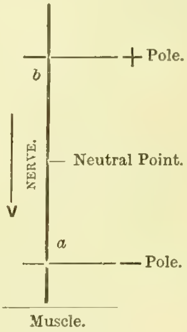
nerve being much lowered, the stimulus is so weak that the muscle does not contract.



2d. Feeble downward current.—Closed, Contraction ; *Opened,* Rest (Pflüger). On closing, a large portion of the nerve next the muscle, *a*, passes into the cathelectrotonic state, the nerve is stimulated, and contraction of the muscle is the result ; but, on opening, a small portion of the nerve, at a distance from the muscle, *b*, passes from the anelectrotonic state, and the stimulation is so weak that the muscle does not contract. But, as already mentioned, p. 172, many physiologists have contraction only on opening and none on closing, a result which is not explained by Pflüger's law. The discrepancy probably arises from the great difficulty of graduating the strength of the current

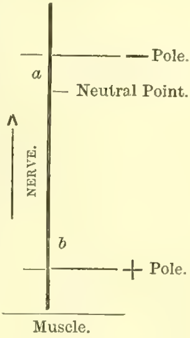
3d. and *4th. Medium upward and downward current.—Closed,* Contraction ; *Opened,* Contraction. In this instance, the neutral point being midway between the two poles, the anelectrotonic and cathelectrotonic areas are equal in extent. On both opening and closing, there is strong contraction, because both anelectrotonus and cathelectrotonus increase with the current strength ; and with the increase in the extent of the anelectrotonic portion, *b*, there is also an opening contraction. On closing, the nerve is stimulated in the neighbourhood of the negative



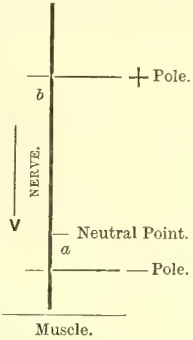


pole, *a*, by the establishment of cathelectrotonus; and on opening, the nerve is stimulated in the neighbourhood of the positive pole, *b*, by the disappearance of anelectrotonus.

5*th*. *Strong upward current.—Closed*, Rest; *Opened*, Contraction. In this instance, the neutral point is near the negative pole, and the cathelectrotonic area is much smaller than the anelectrontonic. On closing, the small portion, *a*, passes into the cathelectrotonic state; the nerve is stimulated, but as the stimulation has not sufficient power to travel along the anelectrotonic portion, *b*, in which the conductibility is much diminished, there is no contraction of the muscle. On opening, the portion, *b*, passes from the anelectrotonic into the normal state, nerve is stimulated thereby, and the muscle contracts.



6*th*. *Strong downward current.—Closed*, Contraction; *Opened*, Rest, or feeble contraction. The closing contraction in this case is caused by the formation of cathelectrotonus in the portion of the nerve, *a*, next to the muscle. But on opening the current, there is usually no contraction of the muscle, or at best a very feeble contraction, because the stimulation arising from the passage of the portion, *b*, from the anelectrotonic to the normal state cannot reach the muscle, owing to the existence in the portion *a* of a peculiar molecular state greatly diminishing its conductibility, termed by Pflüger the *negative modification*.



Another important law, discovered by Pflüger, may be thus expressed, namely,—*The further a nerve is irritated from the muscle, the greater is the excitability of the one, and the contraction of the other.* Two theories have been advanced in explanation. One supposes that the molecules throughout the nerve possess a certain amount of tonic force, a part of which is given off during the transmission of the influence, so that, as the current progresses it receives accumulated intensity, like an avalanche as it rushes down a precipice. The other theory supposes that a motor nerve becomes more excitable the nearer it approaches the nervous centre or its origin, so that an irritant produces a more marked effect when applied there than at a distance.

It must be obvious that the knowledge of the facts now referred to, regarding the varied effects produced in muscles by the strength, direction, and position of the applied current, must be of the greatest importance to the medical man in his endeavours to employ electricity as a therapeutic agent in the treatment of paralysis, neuralgia, and other nervous diseases.

Sensory nerves.—The electrical phenomena of sensory nerves, and the effects of electricity upon them, are the same as those just described relating to motor nerves. Each sensory nerve is excited by electricity in its own special way. Irritation of the optic nerve produces a sensation of light ; of the auditory nerve, sound ; of the gustatory nerve, taste ; of the nasal nerve, smell ; and of the ordinary sensory nerves, pain.*

VITAL PROPERTIES OF THE TISSUES.

While the tissues, as we have seen, possess those properties which, as belonging to matter in general, we call physical, they also possess others which, as only occurring in living bodies, are peculiar and distinctive, and which are denominated vital. These are, 1st. Differentiation in growth ; 2d. Contractility ; 3d. Sensibility ; and 4th. Mental acts, including volition and sensation.

1. *Differentiation in Growth.*—At one period in the history of all vital growths, the individual presented the structure of a finely molecular mass, such as the yolk of an egg, the substance of a seed or spore, or a simple mass of protoplasm or proligerous matter. If we examine two ova, or two seeds of the same size and form, this matter appears to be identical, whether analysed by the chemist, investigated structurally by the histologist, or carefully scrutinized by the physicist, yet from one such

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* Regarding electric taste, sight, hearing, smell, and feeling, see Morgan's "Electro-Physiology," p. 619. For other facts relating to Electro-Physiology, see Morgan *Op. Cit.* ; Du Bois-Reymond, Thierische Elektricität ; Pflüger, Electrotonus ; Heidenhain, Physiologische Studien ; Von Bezold, and Rosenthal, über Gesetz. d. Zuckungen, *Reichert's Archiv.* 1859, p. 131 ; Bland Radcliffe, Lectures on Epilepsy, Pain, Paralysis, &c. London. 1864., &c.

egg may come a swan, and from the other, a goose ; and from one such seed may come a lemon, and from the other, an orange tree. Mammalian ova are comparatively minute in size, and out of two which closely resemble one another may be developed a mouse and an elephant.

Again, if we watch the development of an animal, say a bird, as it is formed within the egg shell, we shall find that out of the molecular matter of the yolk, there is gradually produced membranes, blood corpuscles, blood vessels, the muscular and fibrous tissues, cartilage and bone, nerves and brain, feathers, claws, &c., &c. The physical conditions under which these varied results appear, are usually diffused through the entire germinating mass. The variations seen in the tissues of one animal or plant, as well as those constituting the differences between animals and plants generally are, therefore, the results of what we call a differentiating power of growth. Why the molecular mass forming these yolks of ova should so divide, subdivide, develope themselves into cells which should arrange themselves into tissues, organs, and organisms, so as ultimately to form such different animals and textures, we are profoundly ignorant. A crystal or a mass of rock, may in one sense, be said to grow or increase by aggregation of particles, but these particles are alike, and the differences which exist between different crystals and rocks may, at a very early period, be attributed to varied chemical composition, or physical conditions. The latter distinctions cannot be detected in the case of similar ova and seeds to which we have referred, while the result of development is to produce marked differences in parts. We are therefore obliged to consider the cause of this differentiation in growth to be as yet unknown ; to be a peculiar one, hitherto only found in connection with living bodies, and which therefore, we call vital.

2. *Contractility.*—Elasticity is manifested by forcibly compressing, bending, or drawing out a body, which, on the withdrawal of the external force by its power of recoil, returns to its original form. Contractility is the reverse of this process. The substance is shortened, by an inherent drawing together, or aggregation of, its constituent particles, in the first place, with a certain amount of force which brings bodies, to which its ends are attached closer together, and when the contractile power ceases, the substance is relaxed, and then returns to its original

form. This power in the living economy may be applied to various purposes, not only in the case of muscles, to bring the parts they may be attached to in proximity, but to occasion a variety of other movements, as in the iris, to dilate and contract the pupil, to produce a rapidly moving surface, as with cilia, occasion independent motions, as in spermatozoids and vibriones, amœboid movements, &c., &c.

From the fact that contractility may be seen in simple filaments, as in vibriones ; as in the spermatozoid and cilium ; in isolated protoplasm, as well as in the ultimate fibrillæ of muscle (Fig. 46), it must be clear that this property is attached to the minutest molecules of the tissue. That it was independent of the nervous influence, though capable of being excited through the nerves, was first maintained by Haller, and admits of demonstration in many ways. Thus, first, John Reid, after removing the sciatic nerve from the limb of a frog, exhausted the muscular contractility, by continued galvanic shocks, and observed that while contractility returned after a certain time, sensibility did not. Secondly, E. Weber isolated a fasciculus under the microscope, and still found it contractile. Thirdly, Harless proved that, when sensibility was destroyed by means of ether, to such an extent, that muscular contractions could not be produced by galvanic shocks applied to the nervous centres, they occurred immediately similar shocks were applied to the muscles themselves. Fourthly, plants have no nerves, and yet some of their tissues are contractile. Other arguments may be drawn from the influence of irritants, poisons, and of galvanism on muscles. The various kinds of contractile tissue, are not all induced to contract by the same stimuli. Thus, cold will excite action in the fibres surrounding certain bulbs of the hair, and in those of the dartos, while mechanical irritation and galvanism do not. But mechanical irritation, as well as cold, will cause contraction in the middle coats of the arteries and veins, but not galvanism. All three kinds of irritation act on the fibres of the iris, and contractile coats of the hollow viscera, and the capillary vessels in addition to these, are influenced by certain emotions of the mind, but not by volition. The highest degree of contractility exists in voluntary muscle, which, in addition to all the other stimuli, are contracted through the mind at will.

It must be clear from a consideration of all the facts connected with contractility, that this property is utterly unlike that of elasticity, or other physical phenomena possessed by matter generally, that it is only visible in living tissues, and like differentiation in growth, is therefore a proof of vitality.

Sensibility.—By this term is to be understood that remarkable property of nervous matter, in virtue of which, when it is irritated, a something is produced which we call an influence that is conducted in various directions along the nerves. These nerves, although alike in chemical constitution, ultimate structure, and physical attributes, convey the influences of different impressions, some only in one direction, and others only in another. But further than this, some of these nerves can only be excited or stimulated to produce the influence which is conducted, by one kind of irritant, and others by another kind. Thus, all manner of mechanical irritants, such as pricking, burning, rubbing, pressure, &c., will excite the nerves of common sensibility, while the optic and auditory nerves may be excited by light and sound, which produce little effect on the others. Equally different kinds of sensibility exist in other nerves—some responding to one kind of stimulus, and others to another, and as a result, varied actions produced at a distance from the parts where the irritation was applied. Thus if the influence is conducted by the nerves to the brain, various sensations are produced ; if to contractile parts, varied kinds of movements ; if to the glands, varied sensations ; and if to the tissues, varied alterations in growth, &c. A copper wire, like a nerve, is capable of conveying varied physical influences, such as heat, sound, and electricity, but these influences are generated outside the wire, and simply conducted by it. But when a nerve is struck it generates as well as conducts its own peculiar influence. Apply the point of a needle to a wire no effect results—do so to a nerve, and spasm, pain, a noise or a flash of light may occur, according as the nerve conveys the influence produced to the muscles, the brain, the ear, or the eye. Sensibility, therefore, though in some respects analogous, is broadly distinct from all kinds of physical phenomena ; is only to be recognised in living beings, and, as such, must be considered as essentially vital.

Mental acts, including volition and sensation.—By the mind we understand that property of brain whereby we will, we feel, and we think. Many of the inferior animals will, feel, and think like ourselves, although the degree with which they do the last may differ. An elephant adapts means to an end as the result of thought, often with great sagacity, and the same unquestionably exists in other creatures, in whom it is variously modified, and may be observed imperceptibly to pass into automatic or instinctive actions.

The ancient Egyptians, Arabians, Hebrews, Persians, and Greeks, believed that many of the mental faculties and feelings were seated in the thoracic or abdominal viscera. So old and so widely spread was this hypothesis, that it still keeps a hold of the literature and colloquial language of every people. Hence, the heart, the liver, the spleen, the reins, and the bowels, are among all nations referred to, either literally or figuratively, as so many seats of mental faculties or moral feelings. It was Galen who distinctly maintained that the brain was the organ of the mind and centre of sensation and volition, a view which has been universally held by all distinguished physiologists since his time, and may be regarded as thoroughly established by every trustworthy experiment and observation with which mankind is acquainted. With regard to the relation existing between mind and brain, two views are contended for. One, that the brain originates, the other, that it is only the instrument of, thought. According to the first view, the brain thinks as a muscle contracts, in virtue of a peculiar vital property inherent in its ultimate molecules. According to the second view, the brain is played upon by a hypothetical immaterial agent, as a piano is played upon by a musician. The discussion is metaphysical rather than physiological, because the phenomena observed in every case are the same. It has been well said, "that a piano out of tune will yield discordant music, let the performer be ever so skilful, and that a penny whistle can never have the clang of a trumpet." Whether, then, we regard the brain as a producing organ or as an instrument, everything will depend upon the structure and quality of the instrument itself. There is, however, no more difficulty in regarding consciousness as a property of the brain than there is in considering sensibility to be a property of nerve, or elasticity the property of a steel spring. Of the nature of all these properties, whether physical or vital, we are ignorant. But inasmuch as we never recognise mental acts, except in animals who possess brains, any more than we observe sensibility where there are no nerves, or contractility where there is no contractile substance, so physiologists must regard mental manifestations as functions and properties never present in dead matter, but as characteristic of the highest form of animal life, and therefore as vital.

Relation of the physical to the vital forces.—In studying the different phenomena, whether physical or vital, physiologists are in the habit of using the term force much in the same manner that it is used by the general cultivators of science. Mechanics has its forces, such as that of the lever ; chemistry has its forces, like that of affinity ; and physical science has its forces, like that of attraction. Physiology has also its forces. It has been supposed that in the same manner as we have physical attractions and repulsions, so we have vital attractions and repulsions. Then we have germinative, contractile, nervous, and mental forces. The idea of force, whether in physics or physiology, as explanatory of phenomena, must be regarded only as theory, as a mental creation, which we employ as a convenient term to satisfy that intense desire of arriving at definite causes which is instinctive in man. On the other hand, it is often employed to express action, which may be demonstrated and often measured. In this sense it is as applicable to the action of a stomach or of a liver as it is to that of an electric telegraph or a steam-engine.

Correlation of force.—According to Mr Grove, the physical forces are "correlative," or have a relation of mutual dependence, each being capable of producing any one of the rest, either directly or through the medium of some other. Thus, the motion of a body retarded by friction gives rise to heat ; and, conversely, heat applied to any form of matter produces its expansion,—that is, motion. The friction of two dissimilar bodies produces not merely heat, but electricity ; and heat itself, when made to act on certain combinations of metals, also produces electricity ; whilst on the other hand, the electric current may produce heat, light, magnetism, or motion, according to the nature of the substances through which it is transmitted. Light, heat, and electricity, again, are closely related o chemical affinity, which is often specially excited by them, nd which can in its turn generate these forces ; a material *ubstratum* being required in both cases. In the same way, here may be a correlation of the vital forces. Thus, organic molecular matter may produce various tissues having different vital endowments. That converted into muscular tissue, exhibits contractility ; that converted into nerve, excitability. Here also a certain substratum or material substance is requisite for the conversion of one force into another. Then, as we have seen, there is a certain relation between the nervous and muscular forces : one can call the other into action in a degree proportional to its own excitement ; and, again, nervous agency is capable of influencing growth and cell-formation in such a manner as to give rise to the idea that it may be re-converted into the forms of vital force necessary to evolve cells. Again, heat, light, and electricity have long been recognised as excitors or stimuli of the vital forces, and these, operating through a peculiar organised structure, may in fact become vital forces themselves, just as heat becomes electricity when it passes through a certain combination of metals. Thus, vital force may be converted into physical force, and *vice versa*, as when we see some tissues producing chemical action, others mechanical movement, and a third kind, electricity.

Conservation of force.—Whilst any particular force which is the cause of a certain alteration may be exhausted, there is always another force which gains as much power of producing new alterations in nature as the first has lost. It follows, that although it is the nature of all forces to become exhausted by their own working, the power of the whole system in which these alterations take place is neither exhausted nor increased in quantity, but only changed in form. If a watch is wound up, the active force or energy exerted by the muscles of the arm and hand is communicated to the spring, and this again is communicated to the wheels, and is slowly employed in overcoming their friction for twenty-four hours. But if an arrow be discharged from a bow, then the energy employed by the arm is communicated to the arrow and is expended in half a minute in overcoming the pressure of the atmosphere. Heat, light, electricity, gravity, and chemical action are all in like manner capable of being perpetuated in an unceasing round one to the other. And so in the animal body, the vital forces manifested in various ways are in truth only different forms of energy which originate from the chemical changes produced in the digestion of food, in elasticity, in respiration, or in endosmose. Hence, sensibility, and even the exercise of the mind, cannot proceed without nourishment, and we must regard these manifestations of vital force as only a variety of that chemical force generated in nutrition, as this in its turn is only an altered manifestation of some other force.

It has been shewn that when force is apparently exhausted without doing work, it is not lost, but that heat is generated. Thus, when we stir water rapidly in a bowl, and it again comes to rest, it is increased in temperature. If we try to raise a ton weight, we do not succeed, but become very hot, and the same amount of heat is generated as if, practically applied, would create flame, which the savage does when he expends his muscular energy in rubbing together pieces of dry wood, and so lights a fire. In the animal body the heat so occasioned is at once applied to carry on his functions in various ways, and hence the living frame is enabled to convert more force into work than the most perfect steam engine or other mechanical contrivance. When force or energy is dormant, that is, stored up, as in the compressed air of an air-gun, it is called *potential;* but when it is called into action, and is doing work, as when the same gun is discharged, it is called *actual* or *kinetic.*[*]

Origin of force or energy.—The original source of all energy or force in our universe is THE SUN, because it the great source of heat and light. Under the action of the sun's rays, chemical changes occur in plants, and ternary compounds are formed. The *actual* energy of the sun's rays has become the *potential* energy resident in these compounds. This energy is equal to the heat obtained from their combustion. Animals consume plants, and thus acquire chemical tension or power from them. The *potential* energy of the plant products becomes the *actual* or *kinetic* energy of the animal, which enables the heart to pump blood through the body, and the muscles to produce movement and do work. In the animal body, chemical forces are constantly expended n the production of an equivalent amount of mechanical effect, nd in the generation of a certain amount of heat. An active working man converts in a day a certain amount of carbon nto mechanical effect, and to keep the supply of carbon equal o the demand he must take food. If the work were done at he expense of his muscles alone, Mayer has shewn they would ll be oxidised and consumed in mechanical effect in eighty days. The sum of the heat produced by the mechanical work done by the man in a day, and the animal heat generated during the same time, would be exactly equal in amount to the heat caused by the chemical changes that have taken place in the man's body. Thus "all the world's work, with one exception (tidework), is done by the sun, and man himself, prince or peasant, is but a little engine which *directs* merely the energy supplied by the sun."*

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[*] Professor Tait on Thermo-dynamics, p. 51, *et seq.*

But while physical are essential for the manifestation of vital properties, it should never be forgotten that the former are not identical with the latter. On the contrary, vital have peculiarities which broadly distinguish them from physical phenomena, and admit of easy recognition, as we have seen.

LIFE OR VITALITY.

Definition.—Numerous efforts have been made to define life. Without entering upon a criticism of these, it may be said that they are all faulty. Most authors have felt the necessity of pre-supposing some organised structure, the existence of which is taken for granted in their definitions. Bichat says, "Life is the sum total of the functions which resist death;" Treviranus calls it "The constant uniformity of phenomena, with diversity of external influences;" Lawrence says it consists "in the assemblage of all the functions or purposes of organised bodies, and in the general result of their exercise;" Duges calls it "The special activity of organised bodies;" and Béclard, "Organisation in action;" which last gives us, as far as a short phrase can, what is understood by life.

Theory of Life.—It has been supposed that life was an independent principle, capable of being added to or removed from inert matter. Such was the opinion of the ancient philosophers, as allegorically explained by the fable of Prometheus, who animated the marble statue by fire stolen from heaven. In later times, Buffon imagined life, like matter, to be indestructible. According to him, every living molecule had a life of its own, and the method by which it manifested its function depended on its association with other molecules. Thus, the body of an animal or a plant was the aggregation of a multitude of minute living beings arranged in a particular way. The death of the complex compound was simply a dissolution of one of these associations, and the organic molecules thus set at liberty wandered about until they once more combined with a plant or animal—here with a monad, there with a quadruped. The *materia vitæ diffusa* of John Hunter was something similar.

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* Lockyer, "Astronomy," p. 52. 1870.

Our modern view of life is, not that it is independent of matter, but a condition of matter: in other words, that material substances found in the atmosphere, and in plants and animals, influenced by certain forces, have peculiar properties communicated to them. These properties are the power of growth in certain directions, contractility, sensibility, and mental acts; the exercise of any one of which constitutes life. That accidental causes are capable of communicating one or more of these properties to tissues that did not previously possess them, is certain. Thus, exposure to light may influence the movement of the pigment molecules in the skin of the frog and other animals, so that it at once becomes dark or light. The entrance of a spermatozoid into the ovum—that is a vibratile fibre, much like a vibrio, pushing a molecule before it—excites those changes in the yolk which produce an embryo. An unimpregnated uterus is not contractile, but if impregnated, its fibres have, at a certain period, and then only, a vital property communicated to them, and they expel the fœtus. I think no one can doubt that an aggregation of molecules produce a vibrio, which, at first motionless, has contractility communicated to it, and thereby lives. Moreover on following the development of an animal in an egg, it is capable of being seen, that a portion of the original molecular mass is differentiated, and, by histological and chemical changes, is first transformed into muscle, which afterwards becomes contractile; that another mass is transformed into brain and spinal cord, which subsequently possesses sensibility, and lastly, thought. Thus function, in the embryo, is added to organic matter. Growth differentiated produces organs—each of these has its special functions, which, however, are necessary to the others—so that in every organism there is an incessant round, one organ being necessary to the other, and one form of energy or function capable of being converted into or exchanging with another. (See Correlation and Conservation of Force, pp. 181, 182). A seed may exist for thousands of years as a dried organic mass, but if, at the end of that time, it be put into the earth, it will grow, and thereby lives. It was not alive during the whole of that period, but had the capability of living. Such an organic mass may be compared to a clock ready made and wound up, which requires a touch on the pendulum to set it in movement.

It results that the physical and vital forces and properties are intimately united in a living body, and that the activity or life which it exhibits, is the sum of those phenomena which we observe in it. When, therefore, we use the term life, we simply mean that an organised substance is possessed of certain properties partly peculiar or vital, and partly physical, which, when acted upon by appropriate stimuli, are competent to give rise to that series of actions in which life consists. We are as ignorant of the true nature of physical as we are of vital properties. It is from the effects alone that we infer their existence. Hence, if one substance exhibits the property of combustibility, it burns; if another, on being stretched, returns to its original size, it is elastic; and if a third presents differentiated growth, involving assimilation and excretion, or exhibits contractility and sensibility, it lives.

PART II.

SPECIAL PHYSIOLOGY.

The special functions of the human body may be considered under the heads of Nutrition, Innervation, and Reproduction.

NUTRITION.

Nutrition is very commonly spoken of as a function simply involving the addition of matter to the frame. My object is to shew that it is, in truth, a vast complex process, comprehending not only digestion and assimilation, but circulation, respiration, secretion, excretion, and many others. Even nutrition, in its limited sense, is so essentially connected with the others referred to, that they must all be regarded as a whole or in their relations to one another. Thus digestion and assimilation are not only dependent on the quality and quantity of the aliment, but on the circulation of the blood, on the respiration which gives it oxygen, on the secretions by which food is prepared, and on excretion which removes those things which have served their purpose and would then be injurious. This mode of regarding the function of nutrition is of the utmost importance to the medical practitioner, as it not only leads him to see how nutrition may be deranged in so many ways, but to arrive at the scientific explanation of those complications in diseases which he is constantly meeting with. It must lead him to the conviction that impaired nutrition is to be treated by an endeavour to restore the deranged processes to their healthy state in the order in which they are deranged; that for this purpose a sound knowledge of the process of nutrition itself is a preliminary step; that empirical systems can be of little benefit; and that the only correct basis for medical interference is a comprehensive and true physiology. We shall treat of the various processes subservient to nutrition, therefore, in the order that nutritive matter may be observed to go in, pass through, and come out of the economy. This will be better understood by consulting the view by Bernard, slightly modified, which exhibits in the dog all the organs, with the exception of the skin, concerned in this function. (See Plate IX., fig. 1.)

ALIMENT.

All the various kinds of food are resolvable into the four elements—Carbon, Hydrogen, Oxygen, and Nitrogen, combined with certain mineral bases. The chemical constitution of plants and animals is nearly the same; and hence food derived from one kingdom of nature must contain those substances of which the bodies to be nourished in the other kingdom are themselves made up. The quantity required is principally regulated by the amount of air we breathe, its oxygen uniting with the carbon and hydrogen of the tissues to produce carbonic acid and water, and to evolve the heat of the body. In endeavouring, therefore, to ascertain what are the best kinds of food requisite for meeting the demands of supply, we must pay attention, in the first place, to the chemical principles which enter into the constitution of the living being to be nourished; secondly, to the mode in which these are combined to form tissues and organs; thirdly, to the atmosphere which surrounds it; fourthly, to the amount of waste it undergoes; and, fifthly, to the structure of the animal.

The results of numerous investigations, carried on with a view of determining these points, are as follow:—

1st. The proximate chemical principles required for the nourishment of man are the albuminous, the fatty, and the mineral principles. The first of these are substances rich in nitrogen—such as fibrin, casein, and albumin, which occur both in the vegetable and animal worlds. The second are substances devoid of nitrogen, consisting of the animal and vegetable fats, together with starch, sugar, and gum, which, by deoxidation, are readily converted into fat. The third are mineral salts, more especially phosphate of lime and chloride of sodium. It has been proved that every kind of nutritive food must contain all three principles; and that the absence of any one of these induces starvation and death. Water is also necessary as a diluent.

Magendie fed dogs upon sugar, oil, gum, or butter alone, and found that for one or two weeks they did very well, but after that, became weak, and died on the thirty-second or thirty-sixth day. When they were fed on white bread and water, they lived fifty days; when on cheese and white of egg, they lived longer, but became feeble, emaciated, and lost their hair. The experiments by Edwards and Balzac have shewn that a diet of bread and gelatin is insufficient, producing death after emaciation, without appreciable lesion. A little addition of brown soup, however, renders bread and gelatin highly nutritious. Dr Hammond limited himself to 1½ lbs. of gum on one occasion, and a like quantity of starch on another, with water, per day. Hunger, debility, and fever became so great that he was obliged to abandon the first diet on the fourth, and the second on the tenth day.* When, instead of these substances, he took 1½ lb. of albumin—diarrhœa, albuminous urine, and disgust at the food obliged him to abandon it on the ninth day. Hence it is always necessary to associate a proper mixture of albuminous and fatty principles, in which the mineral, especially chloride of sodium, enters as a constituent part. Of all the articles of food, human milk appears to be that which contains the three essential substances in the best proportions. A like result may be obtained by mixing other articles together, such as fat pork with veal, potatoes with beef, and rice with mutton or fowl. Again, stuffing is generally added to ham and veal, bacon to beans, ham to fowls, and so on. The addition of butter to bread is the almost universal food of the nursery. Mankind have for the most part adopted these rules instinctively. Persons who feed principally on flesh prefer it fat; and those who live largely on vegetables, as potatoes and rice, take considerable quantities of milk. The same result is obtained by the use of fermented liquors. Hence bread and wine constitute a diet resembling milk in chemical constitution.

2d. It is not mere nitrogenous or non-nitrogenous kinds of food that will serve for nourishment, as is theoretically supposed by chemists. To form tissue, these chemical constituents must be converted into albumin and oil, so as to produce those elementary molecules of the chyle which constitute the formative substance of the blood cells ; while the mineral constituents must be dissolved in the fluid in which these float. All three elements exist in every tissue ; but the fibrous tissues abound in albumin, the glandular organs in fat, and the bones in mineral matter. All recent researches, especially those of Lawes and Gilbert, Fick and Wislicenus, Frankland, E. Smith, Parkes, and others, indicate the great importance of the fatty constituents of food.

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* Experimental Researches on Food. Philadelphia. 1857.

3d. The amount of oxygen in the atmosphere greatly influences the quantity of food required. If cold and condensed, more oxygen will unite with the tissues, and more nourishment will be required to meet the demand and prevent waste. If warm and rarefied, the appetite diminishes, and less food is required.

4th. Bodily and mental exercise causes waste of tissue, and active men require more food than those who spend idle lives. An able-bodied labourer requires at least 35 oz. of dry nutritious food; nor can soundness of health be kept up for any length of time under 30 oz. Sedentary people, it is true, exist upon much less ; but they are weak, and generally valetudinarians. Of mixed solid and fluid food, there are required daily between 6 and 7 lbs., of which about 5 lbs. on an average consists of water.

5th. Living beings are governed in their selection of food by laws which the chemist cannot elucidate, and which are essentially connected with structure. It may be true, as Mülder pointed out, that the albumin of vegetables and of animals is the same ; but some animals can only live upon one, and some on the other. The chemist has not explained to us why the carnivora reject vegetable and the graminivora refuse animal food, or why the substances which contain least nutritious matter for one class of creatures are the chief means of support for others. Hence, though chemistry may teach us much, the laws of dietetics can only be arrived at by the physiologist.

6th. Another important fact has been too frequently overlooked, viz., that nutritive substances must have *sapidity* or flavour. Tasteless albumin and oil will not digest, and the reason obviously is, that they fail to excite the secretion of the saliva, which we shall see is so necessary for preparing food.

Hence the value of variety in food, of condiments, of tea, coffee, meat juice, and of numerous other substances, which have been shewn to render that diet nutritious, which without them could not be tolerated. Further—alcohol, wines, and tobacco, under certain circumstances, must also be regarded as nutrients.

Of all the causes of disease, irregularity in diet is the most common ; and of all the means of cure at our disposal attention to the quantity and quality of the ingesta is by far the most powerful.

Hunger and Thirst.—Want of solid aliment produces a peculiar sensation called *hunger*, while want of liquid causes another, called *thirst*. These are not so much dependent on a peculiar condition of the stomach or œsophagus, as they are upon the general wants of the system. Certain animals, when they are large and fat, fall into a torpid state on the approach of winter, and continue so until the warmth of spring returns. During this period they take no food ; their respiration is exceedingly slow ; the blood has rather a gentle undulation than a circulation, and the trivial losses which take place are repaired by the gradual absorption of fat. Hence, at the end of the hybernating season, the emaciation of animals subject to its influence is very considerable. Some authentic cases are known of Indian fakirs who have sustained a complete fast, when in a state of trance, for from four to six weeks ; but such persons have long prepared themselves, and have been supposed, further, to be under the influence of opiates. Under ordinary circumstances, however, complete abstinence from food and drink cannot be supported beyond the eighth or tenth day without danger. Water, or a moist atmosphere, will enable people to live ten or twelve days. Young animals generally sink more rapidly than old ones. Of the 150 individuals wrecked in the *Medusa*, only fifteen survived after thirteen days of starvation ; and some of these had assisted in eating parts of the dead bodies of their companions. One of the most important effects of starvation to attend to is, that after some days it destroys the power of digestion itself to a great extent. Hence the extreme caution necessary in treating such a case. At first only fluids should be given containing little nutriment, the amount of which must be gradually increased.

Excess of hunger causes a disease named *Bulimia*. Captains Parry Franklin, and other Arctic voyagers, relate numerous instances where the Esquimaux devoured with impunity enormous quantities of food. In one case 35 lbs. of meat were consumed in twenty-four hours, besides several tallow candles. The most remarkable instance on record is the one of Tarrari, a soldier described by M. Percy.* On the other hand, some persons from habit have lived, like Cornaro, on a very spare diet. Many of the extraordinary cases of fasting are incredible. Anne Moore, of Tutbury, who pretended to live without any food whatever, on being carefully watched night and day, had scarcely strength enough left on the tenth day to confess the fraud she had practised ; and Sarah Jacob, who was only aged thirteen, when similarly watched, expired on the ninth day.†

MASTICATION.

The food must be properly prepared for the changes it is destined to undergo in the stomach ; and to this end it must be broken down by the action of the teeth, jaws, and tongue.

Teeth.—A description of the teeth belongs to anatomy—their histological structure is described p. 86. All that need be said here is, that the incisor, canine, and molar teeth are organs admirably adapted, in man and in the inferior animals, for seizing, lacerating, and grinding various kinds of food. They are fixed in the jaws, which move about in various directions by the action of the muscles. Man, having a variety of movements, possesses a very complicated apparatus for this purpose.

The first set of teeth which appear after birth commence to be shed about the fifth year, and are called *temporary.* They are twenty in number,—viz., four *incisors*, two *canines*, and four *molars* in each jaw. The permanent teeth are thirty-two in number,—viz., four incisors, two canines, four bicuspids, and six molars in each jaw. The first set are developed within the jaw before birth, but cut through the gums in the following order :—

Incisors.	*Canine.*	*Molars.*
7 to 9 months.	18 months.	12 to 24 months.

The permanent teeth are formed in the jaw below the temporary ones, and both sets exist there at once about the fifth year of extra-uterine life. The latter, however, push out the former, or cause them to be shed in the following order :—

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* See Dict. des Sciénces Médicales. Art. *Cas. Rares.*

† *Brit. Med. Journal,* December 25th, 1869.

	Years.
First molar and central inferior incisor	5 to 7
The same in the upper jaw	6 to 8
Lateral incisors	7 to 9
Anterior bicuspids	8 to 10
Canines	9 to 12
Posterior bicuspids	10 to 12
Second molar	12 to 14
Third molar, or wisdom tooth	17 to 25

As a general rule, the appearance of the lower range precedes the upper.

Tongue.—The tongue continually gathers together the aliment from below the dental arches, and when food is of soft material, assists in crushing it against the palate. To fulfil this function, it not only possesses great mobility, but is endowed with tactile and special sensibility, connected with numerous papillæ (Plate IX., figs. 7, 8, and 9), whereby we are enabled to judge of the physical qualities and situation of aliment in the mouth, as well as to push it about continually, and appreciate the degree of trituration it undergoes. The tongue is also necessary in the acts of suction, speech, and deglutition, and is supplied with five nerves. Of these, the *Hypoglossal*, or ninth cranial nerve, governs the combined muscular movements of its anterior half, although other movements of the organ are regulated by the nerves which influence the muscles of the lower jaw and os hyoides, to which bones it is attached. The function of the *Chorda tympani* (a communicating branch between the facial nerve and gustatory), which terminates in the tongue, is unknown. The sensibility of the organ both to touch and to taste is dependent on the *Gustatory*, or lingual branch of the fifth nerve, n its two anterior thirds, and on the *Glosso-Pharyngeal* nerve n its posterior third. Whether the filaments it receives from he internal laryngeal branch of the *Superior Laryngeal* nerve onnect the tongue more especially with speech, is not known.

Lips and Cheeks.—The lips being closed, they, with the musular walls of the cheeks, assist mastication, in keeping the ood in the cavity of the mouth, and preventing its accumulaion outside the dental arches. They serve also for the prehension of the aliment, for suction, articulation of sounds, and the expression of the passions. The muscles concerned in these actions are under the influence of the *facial* nerve (*portio dura*), while the sensibility of the parts is dependent on the integrity of the sensory branches of the *fifth* nerve. The muscles of mastication—namely, the masseter, temporal, internal, and external pterygoid—are supplied by the motor branches of the *third division* of the *fifth* nerve. The proper muscle of the cheek, the buccinator, is supplied by both the *seventh* and *fifth* nerves.

As the result of these combined operations, the food is broken down, the utility of which must be obvious. All chemical processes, and the action of solvents, is favoured by division of the matter to be operated on. Too rapid eating is a common cause of indigestion ; and considerable masses of food, if not broken by the teeth, pass through the digestive canal unaltered, and deficient nourishment is the result, and this especially if such masses be principally vegetable, or contain the skins of fruit and husks of grain.

INSALIVATION.

In the mouth, masticated food is intimately mingled with the saliva, a viscous fluid, which is secreted from a considerable number of glands.

Salivary Glands.—The true salivary glands are the parotid, submaxillary, and sublingual glands. Scattered over the surface of the mouth and tongue, however, are various others, such as the labial, buccal, palatine, and lingual glands, and the tonsils. Most of these are of the lobulated or racemose variety, terminating in acini, or cæcal pouches, in groups communicating with a duct (Plate IX. fig. 2). Others contain closed sacs, as in the tonsils (Fig. 5), or depressed follicles (Fig. 6). Mixed saliva, on microscopical examination with a power of 250 diameters, may be seen to contain groups of flattened epithelial cells, from the surface of the mouth, mixed with globular nucleated or true salivary cells, shewing Brunonian movements and numerous molecules (Table IX. fig. 3).

Chemical Composition of Saliva.—Water is present in 1000 parts from 995 to 992, and solid residue from 5 to 8 parts. It contains a peculiar animal principle, *Ptyalin*, in from 1 to 4 parts ; epithelial mucus from 1 to 2½ parts ; fatty matters from

$\frac{1}{2}$ to 2 parts; salts from 1 to $2\frac{1}{2}$ parts; and sulpho-cyanide of potassium from ·06 to ·10 parts. Saliva is alkaline.

Functions of the Saliva.—Its uses are—1st, By keeping the mouth moist, to favour articulation; 2d, To assist in mastication, it being much more difficult to break down dry than moist substances; 3d, To facilitate deglutition, as it is impossible to swallow dry matters; 4th, To operate upon certain constituents of the food chemically, and, though there is great difference of opinion as to how this is accomplished, it is supposed to act more especially on the starchy constituents, readily converting them into glucose or grape sugar; 5th, Liebig supposes that, owing to the viscidity of the saliva, air, in the form of froth, is carried to the stomach, and there yields up its oxygen to unite with the tissues or the food.

It is the Ptyalin in Saliva which operates in a peculiar way upon starch, like a ferment, and a very minute portion seems to be sufficient for the purpose. One part converts 2000 parts of starch into dextrin and sugar (Mialhe). Bernard has shown, however, that other animal fluids possess a similar property, but in a more feeble degree. According to him, buccal saliva is a mixed fluid, and originates from three sources, each of which communicates special properties to it. Thus the parotid glands secrete a clear, liquid fluid necessary for mastication; the submaxillary glands secrete a more gelatinous fluid, which is connected with the sense of taste; and the sublingual and palatine glands furnish a viscous, mucous matter, which surrounds the bolus externally, and causes it to slide more easily through the fauces and œsophagus. According to Bidder and Schmidt, about $3\frac{1}{2}$ lbs. of it are secreted daily; but Harley estimates it from 1 to 2 lbs.

Influence of the nervous system on salivation.—The food in the mouth constitutes the stimulus for the flow of the saliva, and the common expression of the idea of a feast making a man's mouth water, shews that the secretion may be excited by mental emotions. According to the experiments of Bernard, and of subsequent investigators, there are two nervous arcs which, through reflex action, excite salivation; the one having for its centre the brain, and the other the submaxillary ganglion. In this way he explained the increased flow of saliva (1.) on irritating the glosso-pharyngeal and lingual nerves in the mouth; (2.) by irritating the facial nerve or the *chorda* *tympani;* (3.) by irritating the muscles of mastication ; (4.) by irritating the fourth ventricle in the brain, or the upper extremity of the sympathetic divided in the neck ; (5.) by mental emotions ; and (6.) by certain poisons operating on the blood, such as the Calabar bean, Mercury, or Woorara. Pflüger describes and figures the extremities of the nerve tubes forming direct communication with the salivary gland cells, but this has not been confirmed by other histologists, and is denied by Heidenhain.*

Deglutition.

The food, reduced to a minute pulp by means of mastication and insalivation, is now carried from the mouth, through the œsophagus or gullet to the stomach (Plate IX. fig 1, A). This is accomplished by a rapid contraction of numerous muscular parts, which unite together to produce the desired effect by the agency of a certain series of nerves acting through the spinal cord; hence called *diastaltic* (δια, *through,* στελλω, *to contract*). So long as the bolus of food is contained in the anterior part of the mouth, it is under the control of the will, but once pushed back by the pressure of the tongue against the hard palate, to the posterior third of the tongue, it is involuntarily conveyed into the stomach. For this purpose the lips are closed, to prevent escape of the morsel anteriorly ; the soft palate is elevated by the *levator palati* and *circumflexus* or *tensor palati* muscles to prevent its passage into the nasal cavities above ; the contraction and backward action of the tongue presses the epiglottis over the larynx, which, however, is closed essentially by the approximation of the true and false vocal cords, and the lapping over these of the epiglottis which touches the posterior wall of the pharynx, as shewn by Czermak with the laryngoscope. This effectually prevents the food from passing into the windpipe inferiorly ; and thus, no other mode of escape being left open, the pressure of the various muscles of the mouth, pharynx, and œsophagus carries it by a continuous wave-like motion from above downwards towards the stomach. The cardiac orifice of the stomach then opens, and the bolus slips through into that viscus. The mucous surface of the œsophagus is kept moist by a series of small compound racemose mucous glands, the secretion from which facilitates the process. (See Plate IX. fig 10).

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* See Sydenham Society's Translation of Stricker's Histology, p. 423, figs. 78, 79, 80, 81, 82; and Heidenhain's Studien des Physiolog., Institutes zu Breslau, 1868.

The nervous influences affecting deglutition will be described under the head of Reflex or Diastaltic Actions.

Digestion in the Stomach.

The stomach is a bag (Plate IX. fig 1, E) in which further mechanical and chemical processes are made to operate upon the food in order to fit it for assimilation or conversion into blood and tissues. It is of various forms in different animals, and more or less complex in its structure. In man of adult age its internal surface has an area of about one and a quarter square feet; its capacity is about one hundred and seventy-six cubic inches or five pints; its weight is seven ounces. In women and children these estimates must be lowered, but they are increased by habitual distension, and by the relaxation of old age, and diminished by exercise, and by the practice of taking small meals (Brinton). The substance of this bag is composed of a serous membrane externally from the peritoneum, a muscular coat in its centre, and a mucous layer internally. The muscular coat is composed of three layers of contractile non-voluntary fibre, which closes upon the food, and subjects it to trituration or kneading, whereby the whole of it is intimately mingled together, and mixed with the gastric juice. It is also pushed about in a certain direction, moving along the great curvature from left to right, and then along the lesser curvature, from right to left. These motions continue until the entire mass of food is broken down into a fine pulp, called *chyme*, which passes out of the stomach through the pyloric orifice. The stomach seems to be more irritable during the period of digestion, and its contractility more energetic; so that a stimulus will operate then which will produce no effect in the interval, or when fasting. Hence is explained why, during digestion, the outward orifice is so firmly closed that nothing but the finest pulp passes through it; but this process once over, undigested masses, and even large bodies, such as coins, have been known to go through. The different motions of the stomach now spoken of have actually been seen to take place in the living human body, in a remarkable case, the study of which has so improved our knowledge of this function that it deserves especial notice.

Case of St Martin.—St Martin was a Canadian, eighteen years of age, who, when in perfectly good health, was accidentally wounded by the discharge of a musket on the 6th of June 1822. "The charge," says Dr Beaumont, "consisting of powder and duck-shot, was received in the left side, at the distance of one yard from the muzzle of the gun. The contents entered posteriorly, and in an oblique direction, forward and inward, literally blowing off the integuments and muscles to the size of a man's hand, fracturing and carrying away the anterior half of the sixth rib, fracturing the fifth, lacerating the lower portion of the left lobe of the lung, the diaphragm, and perforating the stomach." From this injury he gradually recovered, but the orifice never closed. When healed, twelve months after the accident, the perforation was two-and-a-half inches in diameter. Subsequently a small fold of the mucous coat of the stomach appeared, which gradually increased till it filled the aperture, and acted as a valve, so as completely to prevent any efflux from within, but to admit of being pushed back by the finger from without. Dr Beaumont, who had carried this difficult case to a successful termination, took the man into his service, and commenced a series of careful observations, which he has embodied in one of the most instructive works extant on the subject of digestion. On placing a solid substance through the opening into the stomach of St Martin, it was seen by Dr Beaumont to be subjected to the movements described.

Other cases of permanent openings into the human stomach have since occurred. That of an Esthonian peasant—a woman, aged 33—came under the observation of Bidder and Schmidt, who made several observations upon her. Two others I have seen myself, but their general health was so bad as to prevent the possibility of watching the process of digestion in them with any advantage.

The movements of the stomach, though useful in perfecting and facilitating digestion, do not constitute the essential part of the process, as was shewn by the experiments of Spallanzani, who caused perforated metallic balls to be swallowed, filled with food, which, notwithstanding the absence of trituration, was perfectly digested in the stomach.

Influence of the nervous system on digestion.—Dr John Reid ascertained on cutting both *vagi* nerves, that the food was only digested towards the circumference of the mass, where it was in contact with the coats of the stomach. His experiments, however, were performed on herbivorous animals (horses, asses, and rabbits) where the food is bulky and difficult of solution, requiring to be constantly changed in its position. On repeating the experiments on dogs fed upon flesh, he found the food perfectly digested after action of the *vagi*. The movements of the stomach, therefore, though useful in all animals, and necessary in some, do not furnish the essential conditions for digestion, which are supplied by the gastric juice and a suitable temperature.

The structure of the gastric mucous membrane. It is composed of tubules from ¼ to 1 line in length, and about 1·300th of an inch in diameter, running parallel with, and closely applied to, each other. Their shut bases rest on the submucous tissue, and their open extremities are directed towards the cavity of the stomach, where groups of from three to six open in slight polygonal depressions on the surface called *alveoli* (Plate X. *a*, fig. 1). The open mouths of these glands are somewhat constricted, the amount of this, however, varying with the distension or contraction of the viscus (fig. 2). On being magnified 250 diameters linear, they may be seen to be of two kinds, one lined with columnar epithelium throughout, most abundant near the pylorus, and supposed to secrete only mucous (Plate X. fig. 8) ; the other only lined by columnar epithelium above, and containing molecules and cells below, which form the gastric juice. These latter tubes exist over the cardiac and middle portions of the stomach, and on careful examination will be found to contain molecules, nuclei, and cells in different stages of formation, as figured by Frerichs. (See Plate X. figs. 3, 4, 5, 6, 7.) The large cells which secrete the gastric juice are seen *in situ*—figs. 6 and 7, and isolated, fig. 9. It is those cells containing the gastric juice which are poured forth in enormous numbers during the period of digestion, and, by their rupture, yield the peculiar acidulated organic fluid so essential for the process. In the intervals of digestion, fresh cells and juice are secreted within the follicles, and the reaction of the inner lining of the stomach becomes neutral or alkaline. Shut sacs, like those of Peyer's glands, are also found in the mucous membrane of the stomach, most numerous near the pylorus, and best seen in the stomachs of infants and children (Pl. X. fig. 10).

The *conditions favourable for good digestion* in the stomach are —1st, A temperature of about 100° Fahr. = 37·7° Cent. ; 2d, Constant movement of the walls of the stomach, which brings in succession every part of the food in contact with the mucous membrane and gastric juice ; 3d, The removal of such portions as have been fully digested, so that what remains undigested may be brought more completely into contact with the solvent fluid ; and 4th, A state of softness and minute division of the aliment. Numerous experiments have shewn that digestion will go on in gastric juice out of the stomach, but that it takes three or four times longer a period than when performed by stomach itself. (See Gastric Juice, p. 202.)

According to the experiments of Dr Beaumont upon St Martin's stomach, the rapidity of digestion varies according as the food is more minutely divided, whereby the extent of surface with which the gastric fluid can come in contact with it is proportionally increased. Liquid substances are for the most part absorbed by the vessels of the stomach at once, and any solid matter suspended in them, as in soup, are concentrated into a thicker material before the gastric juice operates upon them. Solid matters are affected so rapidly during health, that a full meal, consisting of animal and vegetable substances, may be converted into chyme in about an hour, and the stomach left empty in two hours and a half. Dr Beaumont found that among the substances most quickly digested were rice and tripe, both of which were digested in one hour. Eggs, salmon, trout, apples, and venison were digested in one hour and a half ; tapioca, barley, milk, liver, and fish, in two hours ; turkey, lamb, and pork, in two hours and a half. Beef, mutton, and fowls required from three to three and a half hours, and these were more digestible than veal. These facts were different from what was anticipated, and shew that prevailing notions as to the digestibility of different kinds of food are very erroneous. It must be remembered, however, that easy digestibility does not imply high nutritive power. A substance may be nutritious, though so hard as not to be readily broken down ; and many soft, easily digested materials may contain a comparatively small amount of nutriment.

Other circumstances besides those referred to affect digestion in the stomach. Among these are—1st, The quantity of food taken : the stomach should be moderately filled, but not distended ; 2d, The time which has elapsed since the last meal, which should always be long enough for the food of one meal to have completely left the stomach before more is introduced ;

3d, The amount of exercise previous and subsequent to a meal, —gentle exercise being favourable, and over-exertion injurious to digestion; 4th, The state of mind,—tranquillity of temper being apparently essential to a quick and due digestion; 5th, The bodily health; 6th, The state of the weather; 7th, Period of life,—digestion being more active in the young than in the old.

DIGESTION IN THE INTESTINES.

The intestines have been divided into small and large, and each of these subdivided into three portions. Thus the small intestine is divided into duodenum (see Plate IX. fig. 1, I), jejunum (K), and ileum (L); and the larger intestine into cæcum (M), colon (N), and rectum (O). The whole constitutes a hollow tube, with serous, contractile, and mucous coats, similar to but not identical with those of the stomach. The food operated on in the manner described enters the upper part of this tube—the duodenum—in the form of a thick, grumous fluid, *chyme*, of a strong, disagreeable acid odour and taste, and containing undigested portions of the food. This is now propelled from above downwards by the action of the contractile fibres of the intestine. As it descends, it is subjected to two kinds of operations—1st, The influence of various fluids with which it is mixed; and 2d, The gradual absorption of its nutritive substance through the intestinal walls into the system.

Shortly after the chyme has passed out of the stomach, it becomes mixed with the bile and pancreatic juice—two fluids secreted respectively by the liver and the pancreas, which in man enter the duodenum by a common opening. The exact influence exerted by the bile on the chyme is not accurately known; but it is supposed to neutralise somewhat the gastric juice, and so to operate as to render the nutritive and excrementitious matter more easily separable. The bile serves other purposes in the economy, which will be dwelt on subsequently. The pancreatic juice is a clear alkaline fluid, which has the property, when mingled with a drop of oil, of emulsionising it with the greatest readiness. Numerous observations and experiments by M. Bernard have shewn that it operates with the greatest readiness on the fatty constituents of the food; and that in such animals as have the pancreatic separated from the biliary duct for some distance, as in the rabbit, milky chyle is only formed in the lymphatics after the food has passed the former. Hence there can be little doubt it does emulsionise the fluid fat of the food, and fit it for assimilation. At the same time, recent observations shew that this is not its exclusive action, but that it also assists in digesting the other constituents which have escaped the operations of the mouth and stomach. The chyme is also mingled with the fluid of the Brunerian glands of the duodenum, which are true compound racemose glands (Plate X. fig. 12), and of the glands of Peyer and Lieberkühn (Plate X. figs. 10, 11, 13, 19, 20, 21), scattered over the small intestine generally.

As the chyme passes along the intestinal canal from above downwards, it is squeezed by successive contractions of the tube forcibly against the mucous coat of the intestine. This is covered with prominences of various forms and lengths, denominated *villi*, which are pendulous folds or projections of the mucous coat itself, covered by epithelium, and enclosing blood vessels, one or more lacteal vessels, and fine muscular fibres, so that they present a great extent of surface, over which the chyme passes (Plate X. figs. 12, 13, 14, 20, 21). The more fluid parts, containing such portions of the food as have been reduced to excessive fineness, now pass through the membrane, and enter a series of ducts provided for that purpose. (See *Chylification.*) As the chyme, therefore, descends the alimentary tube, it is constantly losing its more fluid and nutritive portions, while other portions of it are being still farther digested and prepared for a like absorption. On reaching the cæcum, or commencement of the large intestine, it assumes a fæcal odour, and has now lost nearly the whole of its nutritive matters. Such as remain, however, are absorbed by the large intestine, whilst the useless matter becomes more and more solid, until it is expelled through the rectum. Supposing that 30 oz. of solid nutriment have been taken in the course of twenty-four hours by a healthy individual, only 5 oz. of these are expelled as fæces ; so that 25 oz. have been prepared, elaborated, and finally passed into the body to form blood, and through it into the various tissues and secretions, to supply the wants of the economy.

Digestive Fluids.

1. *The saliva.* (See p. 194.)

2. *The gastric juice* is slightly acid, and contains a peculiar animal principle, *pepsin.* It has been much disputed by che-

mists whether the acid be hydrochloric or lactic. Probably, sometimes the one, and sometimes the other, is in excess. (See p. 11.) The gastric juice has an extraordinary solvent power on the albuminous constituents of the food, as well as on gelatin, chondrin, and gluten, which, when dissolved in it, produce a material called *peptone.* One part of pepsin dissolved in 60,000 parts of water will effect this. In children, and in healthy adults dying suddenly after a full meal, the gastric juice often acts upon the coats of the stomach after death, when its most dependent part, where the fluid gravitates, is dissolved. The gastric juice has no further influence on fatty substances than that of liquifying them ; so that the albuminous and fatty constituents of the food pass into the duodenum in a liquid state, mingled with broken-down portions of animal and vegetable substances, in the form of a pulp called *chyme.* This is then mingled with the bile and pancreatic juice.

3. *The bile* is a slightly alkaline, opaque, and brown-coloured, bitter, ropy fluid, which neutralises the action of the gastric juice, and renders albuminous substances again soluble. It contains cholestrine, taurochocolate, and glycochocolate of sodium and potassium, fats, salts of fatty acids, mineral salts, and colouring matter. (See Chemistry of the Tissues, pp. 12, 16, 17, 19, 32, 33.) Place a piece of meat in a glass vessel with some gastric juice, and it will soon become digested ; but if a little bile be added, the digestive process is suddenly arrested. The gastric juice preserves its acidity, but loses its digestive power. This, according to Bernard, depends upon the precipitation of its pepsin. Certainly a yellow deposit is thrown down, which adheres to the sides of the intestine, and which is only again rendered soluble by the other intestinal fluids. It is owing to this property of the bile that digestion is at once arrested when any of it regurgitates into the stomach, causing loathing for animal food, nausea, eructation of bile and vomiting, or so-called bilious symptoms. (See Excretion from the Liver.)

4. *The pancreatic juice,* according to Bernard, is a colourless, viscid, clear fluid, which becomes frothy on agitation, and is invariably alkaline. Exposed to heat, it coagulates firmly and universally, as it does also on the addition of nitric, sulphuric, and hydrochloric acids. It contains a protein substance, which has all the powers of the secretion, called *pancreatin,* a small amount of mineral salts, extractive matters, and some fat. It

possesses in a high degree the power of emulsionising fluid fats. (See p. 118.) It also changes amylaceous matters into sugar within the intestine, and may assist in disintegrating the bile, and rendering it more of an excretory product.

5. *The intestinal juice*, secreted by the Brunnerian and other glands of the intestine, has been shewn by Bidder and Schmidt to be capable of dissolving the albuminous constituents of the food which have escaped the solvent action of the gastric juice. How far the glands of Brunner may influence digestion differently from those of other intestinal glands, has not yet been determined.

The quantity of the fluids secreted daily is, according to Bidder and Schmidt, as follows :—

Saliva . . .	3·5 pounds.
Bile	3·5 ,,
Gastric juice . . .	14·1 ,,
Pancreatic juice . .	0·44 pounds.
Intestinal juice . .	0·44 ,,

The large quantity of these five digestive fluids, amounting to about 22 lbs. daily, contains little solid matter. They are evidently designed to dissolve and act chemically on the aliment. While some of them operate more especially on one kind of substance, others do so more particularly on another, at the same time that they are not exclusively directed to one object. Thus the pancreatic juice may do other things besides emulsionising fat, and the intestinal juice may perform lower down in the canal what the stomach has failed to accomplish. Then the importance of the peristaltic movements of the intestines must not be overlooked, which intimately mix the food with the different secretions, and constantly propel the mass from above downwards along the tube. Lastly, all the various processes are necessary to and assist one another. The saliva, when swallowed, stimulates the secretion of gastric juice, as does this in its turn the flow of the bile, pancreatic, and the intestinal juices; and hence why indigestion may arise from a permanent excess, diminution, or perversion of any of these secretions, as well as of the nervous or muscular actions concerned in the digestive process.

CHYLIFICATION AND SANGUIFICATION.

The food, prepared and acted upon in the manner described, is gently propelled by the peristaltic contractions of the alimentary canal along its interior, and is at the same time pressed against the numerous villi that project from all parts of the mucous surface. These organs, covered with a layer of conical or cylindrical epithelial cells (Plate X. figs. 14 and 15), imbibe the more finely molecular particles of the chyme, which pass through the delicate walls of the cells, and may be seen shortly after digestion collected in their interior. The watery fluid of the chyme is for the most part absorbed by the blood vessels.

By some it is thought that the fine lines seen on the broad extremities of the cells are minute canals (Plate X. figs. 14 and 17), through which the matter passes (Kölliker). Others suppose they are embryonic, or not yet separated cilia, and analogous to the structure of similar cells seen on the respiratory mucous membrane (Gruby and Delafond). According to Heidenhain, Brücke, and Funke, there is a direct connection between the epithelial cells covering the villi and the chyle duct, as seen in Plate X. fig. 22. Letzerich, on the other hand, supposes that flask-shaped bodies, which occur here and there among the epithelial cells, are the only absorbing parts, and that these are connected directly with a plexus of minute chyle vessels which terminate in the larger one in the interior of the villus, as seen Plate X. fig. 23. All these views have been disputed ; and, indeed, the histological inquiry is one of great difficulty. It is most probable that the passage of the molecular matter from the chyme into the epithelial cells is owing to endosmose, assisted by the mechanical pressure exercised by the muscular walls of the intestine. The mechanism of the transmission of the molecular chyle into the primary chyle duct is as yet unknown.

The molecular fluid so derived from the chyme, and absorbed into the chyle vessels of the villi, now passes through the lymphatic glands, and receives contributions from them and others, the whole of which may be regarded as secreting the blood, and are, therefore, called the *blood glands.* These consist of the lymphatic glands generally, of the glands of Peyer, of the spleen, *supra renal* capsules, thyroid and thymus glands, and of the pituitary and pineal glands.

The lymphatic glands.—A lymphatic gland consists of a cortical and medullary portion, composed of pouches or sacs separated by fibrous tissue, and surrounded by a firm fibrous membrane, which is richly supplied by blood-vessels. The interior of these pouches or sacs, which communicate with each other, contains a molecular fluid, in which numerous nuclei and a few cells may be found in all stages of development. (See Plate X. fig. 24). According to His, there is a space left around the gland pulp, between it and the wall of the sac, which he terms the *lymph sinus* or *lymph channel.* The afferent lymphatics terminate in the lymph sinuses of the cortical portion, while the efferent commence in those of the medullary portion. These glands are widely distributed throughout the body, and are connected together by lymphatic vessels, having valves in their interior, which only admit of the fluid they contain passing in one direction. (Plate X. fig. 25.)

The glands of Peyer.—I agree with Brücke in considering as the first series of lymphatic glands. They are scattered over the intestinal mucous membrane from the stomach to the rectum, and may be solitary or aggregated together in patches, the latter become larger as they descend the small intestine. They consist of a shut sac composed of fibrous tissue, and contain numerous molecules and nuclei and a few cells, or so-called lymphatic elements. (See Table XI. fig. 19, 20, and 21.)

The spleen.—This organ is composed of a fibrous envelope which sends in fibrous bands or trabeculæ uniting with one another, so as to divide its substance into irregularly-sized spaces filled with a reddish pulp. The pulp consists of nuclei and cells, mingled with blood corpuscles isolated or grouped together—often surrounded by an albuminuous envelope—in all stages of disintegration. The trabeculæ contain numerous nucleated fusiform cells. It is richly supplied with lymphatics and blood vessels. Connected to the coats of the smaller arteries are shut sacs, from the one-thirtieth to the one-sixtieth of an inch in diameter, exactly like the glands of Peyer, called the *Malpighian bodies of the spleen*, containing lymphatic elements. (Plate XI. fig. 1.)

The supra-renal capsules consists of a cortical and medullary substance, the former contain elongated shut sacs varying in size, lying side by side, and contain the same lymphatic elements as the glands of Peyer and the Malpighian bodies of the spleen.

(Plate XI. fig. 2.) The medullary portion is essentially fibrous, with granular cells embedded in its substance. Dr Addison considered that disease of these organs produced a dark brown or sallow tint in the skin, and there can be no doubt that the two do often coincide. But the exceptions are so numerous as to prevent our belief in the necessary connection between one and the other.

The Thymus gland consists of hollow lobules or pouches united together by fibrous tissue, and filled with the same lymphatic elements as exists in the other blood glands. They all communicate with a central reservoir from which there is no outlet. It is large in the human infant shortly after birth, but in a few years commences to diminish in size, and after puberty is converted into a mass of fat. Hence it is only active as a blood gland during early childhood, and loses its glandular character as age advances. (Plate XI. figs. 4 to 8.)

The Thyroid gland consists of a dense fibrous stroma, embedded in which are numerous shut sacs filled with the same lymphatic elements we have referred to, and occasionally lined by a distinct membrane with adherent epithelial cells. It also, like the thymus, is comparatively large in infancy, but in adult age degenerates not so much like that gland by fatty degeneration, as by the deposition into the shut sacs of colloid or glue-like matter. (Plate XI. fig. 3.)

The Pituitary and Pineal glands, in their general structure, resemble the glands just noticed, being composed of fibrous tissue enclosing shut sacs, the latter containing calcareous deposits. This renders it probable that at an early period of life they performed similar functions to the blood glands.

All these organs resemble one another in structure, containing pouches or shut sacs, rich in a molecular fluid and multitudes of naked nuclei. They have no ducts, are very vascular, and are connected with the thoracic duct by numerous minute channels or lymphatics. No difference whatever can be distinguished between the glandular contents of these organs and those of the lymphatic glands; and other facts connected with their morbid states—more especially the production of leucocythæmia—serve to convince us that, like them, they are connected with sanguification; hence their modern name of blood glands. The whole system of lymphatic glands may be said to secrete or form the blood corpuscles, although the nature of the blood, as a whole, being very complex, cannot be clearly understood until we study the results of the secondary digestion.

All these lymphatic glands produce changes in the chyle as it is obtained from the chyme. Peyer's glands operate upon it first. These are succeeded by the lymphatic glands in the mesentery, and are further influenced by the spleen, *supra-renal* capsules, and other glands. All of them are connected with one another by lacteals, which ultimately terminate in the thoracic duct. They serve to subject the molecular chyle as it is first derived from the chyme to the action of these glands. There the onward flow of the fluid is somewhat delayed ; an exchange takes place between it and the surrounding blood, and nuclei and cells are formed—more especially, however, nuclei—by molecular aggregation. Hence why, on cutting into these glands shortly after digestion, and examining microscopically the fluid they contain, it may be seen that a molecular fluid (first described by Gulliver) is more or less crowded with naked nuclei, which resist the action of acetic acid. On repeating the observation on fluid taken from the thoracic duct the same thing is noticeable, only several of the nuclei are now flattened, and in every point, except colour, closely resemble the blood corpuscles (Plate III. figs. 1 and 2). It is clear, therefore, that chylification and sanguification are perfected through the action of the lymphatic glands upon the molecular chyle ; that in them the blood corpuscles are formed, and conveyed by the thoracic duct into the circulation at a point not far from the right side of the heart ; from thence they are rapidly propelled into the lungs, where, on being exposed to the oxygen of the atmosphere, they assume colour, and thereby become the coloured corpuscles of the blood.

LEUCOCYTHÆMIA.

This condition of the blood, consisting of a marked increase in its colourless cells from diseased blood glands, I discovered in 1845, in a case of hypertrophy of the liver, spleen, and lymphatic glands. At that time the subject of inflammation and pyæmia was engaging the attention of pathologists. By W. Addison and Williams, it was maintained that an increase in the colourless cells was the cause of inflammation. Piorry talked of a hæmatitis, or inflammation of the blood, as a cause of pyæmia, by which expression others meant absorption into and admixture of pus with the blood. All these views were at once overthrown by the publication of my case, which demonstrated the admixture of numerous colourless cells identical with those of pus in the blood without inflammation or pyæmia. The name given to these corpuscles is of little importance. Call them pus cells, colourless cells, or leucocyths after Robin ; speak of the fluid in which they occur as a purulent fluid, as leukhæmic fluid, or as a leucocytotical fluid (!) (see Virchow's "Cellular Pathology," p. 167), the cells and the fluid are still the same. But to shew that, whatever term be employed, the cells and fluid containing them were in no way connected with inflammation, was an important step in pathology. My case proved, as I stated at the time, "that pus can form in the liquour sanguinis within the vessels *independent of inflammation.*" But as the words pus and suppuration were apt at that time to mislead, I subsequently proposed the expression *leucocythæmia* (λευκὸς, white ; κύτος, a cavity or cell ; αἵμα, blood), or white cell blood, because it "expresses the simple fact, or a pathological state, and involves no theory."

Six weeks after the publication of my case, Virchow published a similar one,* with the following introduction :—"In the older authors observations occur here and there concerning blood which had so completely lost its colour that it was likened to milk, chyle, mucus, or pus. The communication of the following case will confirm this apparently fabulous statement." The fact that struck him most was the colourless condition of the blood. He therefore called it "leukhæmia," or white blood ; and although epistaxis occurred before death, and the blood was seen to possess its natural colour, he is led by this to the conclusion, "that the remarkable transformation of the red blood into white *can only have occurred to that degree in the latest stages, for the blood of the epistaxis was always red!*" The truth is, however, that in this disease, the blood during life is never white. The coagula after death are white or colourless ; but so they are in a variety of affections where coagulation takes place slowly.

Thus, while I endeavoured to prove that a new morbid condition was independent of inflammation, Virchow sought to establish the doctrine of a "white blood," originally put forth by Hippocrates, who supposed that this, with the other yellow, red, and black bloods, produced the four temperaments. The real white blood—that is, milky or chylous blood—had been long known, and is not only different in itself, but is owing to different causes. This was clearly shewn in a discussion of the Academy of Medicine in Paris, January 29th 1856, where the term "white blood" gave rise to the greatest confusion, the most distinguished chemists maintaining they had been familiar with it (that is fatty blood) long before my observations on leucocythæmia, or white cell blood, were known.

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* Froriep's Neue Notizen, November 1845.

In 1845, I pointed out that the colourless cells found in the blood were identical with those of pus. This, though denied at the time by others, is now universally admitted. Distinctions, it is true, have sought to be established between their existence outside and inside the vessels (Virchow), but these have completely failed, while Cohnheim and others have recently endeavoured to shew that the pus corpuscles originate *inside* the vessels, traverse their walls, and accumulate *outside* to constitute suppuration. I still believe, however, as I did in 1845, that it is only when these bodies accumulate in the blood vessels, independently of inflammation, that the lesion is of a novel character. *That* is the real question to be considered as throwing importance on sanguification, and the function of the blood glands.

The importance of this discovery, indeed, is now manifest, not only as demonstrating that admixture of colourless or pus cells with the blood in great numbers was not the cause of inflammation nor of the so-called condition of pyæmia, but in confirming the views of Hewson as to the origin of blood corpuscles in the lymphatic glands, which up to that time had not been received in physiology. In a paper read to the Royal Society of Edinburgh in 1852, and in a separate work on Leucocythæmia, I directed attention to this matter.* The disease is always connected with hypertrophy in one or more of the blood glands. In health, as we have seen, these form the blood corpuscles. When hypertrophied, many of the nuclei, which, as such, constitute the coloured corpuscles, are in these glands formed into cells, and, entering the blood, thereby increase the amount of the colourless cells in that fluid, and diminish the number of coloured nuclei. It is to be regretted that, though acquainted with these facts, and my writings on the subject, Professor

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* Leucocythæmia, or White Cell Blood, in relation to the Physiology and Pathology of the Lymphatic Glandular System. Edinburgh. Royal 8vo. Plates. 1852.

Virchow, when revising his work on "Cellular Pathology" for the English press, should have published as follows :—"A good many years elapsed (after 1845), during which I found myself pretty nearly alone in *my views.* It has only been by degrees, and indeed, as I am sorry to be obliged to confess, in consequence rather of physiological than pathological considerations, that people have come round to those ideas *of mine*, and only gradually have their minds proved accessible to the notion that, in the ordinary course of things, *the lymphatic glands and the spleen are really immediately concerned in the production of the formed elements of the blood.*" ("Cellular Pathology," by Chance, 1860, p. 172.)

The fifth chapter of Hewson's work, containing an account of the manner in which the red particles of the blood are formed (p. 274, Sydenham's Society's edition), may be referred to for a complete refutation of this claim of Professor Virchow. Hewson says, concerning the production of the formed elements of the blood (section 108, *op. cit.*, p. 285): "But if we allow the spleen to make the red part of the blood, we can readily account for the reason why the spleen may be cut out of an animal and yet the animal survive and suffer but little inconvenience ; for though the *office of the spleen is to form the red particles of the blood*, yet it is not the only organ in the body capable of doing that office, *for we have already proved* (sections 85 and 88) that the lymphatic vessels do also form the vesicular portion ; the spleen, therefore, is not the only organ capable of doing it," &c.

It follows—1st. That Professor Virchow cannot claim the discovery of leucocythæmia as a matter of fact and observation, because the first case of it was carefully described and published by myself, six weeks before he wrote on the subject, and was separated from all known lesions as suppuration of the blood independently of inflammation, an idea previously unknown. 2d. That he cannot claim it in consequence of calling it "white blood," as this was spoken of by the ancients, and is everywhere known as the milky or chylous blood of authors. 3d. That he cannot claim it on the ground that the colourless cells of the blood are different from those of pus, as it is admitted by himself that they are identical. 4th. That he cannot claim it on the ground that he first pointed out the blood corpuscles, coloured or colourless, to be derived from the spleen and blood glands, as this was unquestionably made out by Hewson nearly a century ago.

CIRCULATION OF THE BLOOD.

Having seen how the nutritive elements of the food are converted into blood, we have next to describe the method by which that fluid is distributed or circulated throughout the organism. This circulation is carried on through the heart, the arteries, the capillaries, or intermediary vessels and veins, back to the heart again. In the higher animals there may be said to be two circulations, one connected with the body generally—the *systemic* or greater circulation ; the other with the lungs—the *pulmonary* or lesser circulation. Let us suppose that it commences with the left ventricle of the heart. (See Plate IX. fig. 1.) The blood passes from thence by the aorta through the systemic arteries into the capillaries, and back by the veins to the right auricle of the heart. From thence it goes into the right ventricle of the same organ, through the pulmonary artery to the capillaries of the lung, in which it is exposed to the atmosphere, and then back through the pulmonary veins to the left auricle and left ventricle, where we saw that it commenced. In this constant round it is subject—1st. To various forces which serve to propel it ; and 2d. To different changes, the result of the respiratory and nutritive processes.

Forces producing the circulation.—The most important force which propels the blood is induced by the contractions of the muscular walls of the heart,—an organ so constructed that, by the union of contractile cavities and valves, the fluid is constantly sent through it only in certain directions. The action of this apparatus is accompanied by certain noises, caused by the combined contraction of the muscular walls, the rushing of the fluid and the flapping together of the valves,—an exact appreciation of which is the method by which the modern physician is enabled, with wonderful accuracy, to determine the diseases or derangements of the organ.

The heart sounds.—On placing our ear over the cardiac region in a healthy person, we feel a beating, and hear two sounds, which have been likened to the tic-tac of a watch, but to which they bear no resemblance. They may be imitated, however, very nearly, as pointed out by Dr Williams, by pronouncing in succession the syllables *lupp*, *dupp*. The first of these sounds, which is dull, deep, and more prolonged than the second, coincides with the shock of the apex of the heart against the thorax, and immediately precedes the radial pulse ; it has its maximum intensity over the apex of the heart—below and somewhat to the inside of the nipple. The second sound, which is sharper, shorter, and more superficial, has its maximum intensity nearly on a level with the third rib, and a little above and to the right of the nipple—near the left edge of the sternum. These sounds, therefore, in addition to the terms *first* and *second*, have also been called *inferior* and *superior*, *long* and *short*, *dull* and *sharp*, *systolic* and *diastolic*— all which expressions, so far as giving a name is concerned, are synonymous. The two sounds are repeated in couples, which, if we commence with the first one, follow each other, with their intervening pauses, thus—1st. There is a long, dull sound coinciding with the shock of the heart ; 2d. There is a short pause ; 3d. The short, sharp sound ; and 4th. A longer pause,—all which correspond with one pulsation. In figures, the duration of these sounds and pauses by some have been represented thus—the first sound occupies a third, the short pause a sixth, the second sound a sixth, and the long pause a third. Others have divided the whole period into four parts ; of which the two first are occupied by the first sound, the third by the second sound, and the fourth by the pause. The duration as well as the loudness of the sounds, however, are very variable even in health, and are influenced by the force and rapidity of the heart's action, individual peculiarity, and form of the thorax. Their extent also differs greatly. They are generally distinctly heard at the precordial region, and diminish in proportion as we withdraw the ear from it. They are less audible anteriorly on the right side, and still less so posteriorly on the left side. On the right side posteriorly they cannot be heard. Their tone also varies in different persons ; but in health they are free from a harsh or blowing character.

Great diversity of opinion has existed regarding the causes of these sounds, but we may consider that there coincides with the first sound—1st. The impulse, or striking of the apex against the thoracic walls ; 2d. Contraction of the ventricles ; 3d. Rushing of the blood through the aortic orifices ; and 4th. Flapping together of the auriculo-ventricular valves. There coincide with the second sound—1st. Rushing of the blood through the auriculo-ventricular valves ; and 2d. Flapping together of the aortic valves. Contraction of the auricles immediately precedes that of the ventricles. The result of numerous pathological observations and of many experiments is, that in health the first sound is produced by the combined action of the auriculo-ventricular valves, of the ventricles, and of the rushing of the blood, which sound is augmented in intensity by the impulsion of the heart's apex against the thorax; whereas the second sound is caused only by the flapping together of the sigmoid valves.

Order of succession in the action of the heart.—During the long pause the whole heart is in a passive state. The auricles, however, are gradually filling with blood, a portion of which escapes into the ventricles ; but at the end of the pause they contract suddenly, and nearly the whole of their contents is propelled into the ventricles. This amount of blood, added to that which had previously escaped from the auricle, distends the ventricles and closes the auriculo-ventricular valves. The ventricle now contracts, but more slowly than the auricles, so that the apex becomes shorter and rounder. The fleshy columns contract at the same moment, causing the closed mitral and tricuspid valves to become tense, and the blood rushes through the arterial orifices, pressing back the sigmoid valves. During the short pause, the resistance offered by the elastic large arteries is such, that a recoil of a portion of the blood is produced, which flows backwards, distending the semi-lunar valves, and causing the second sound. The distension and closure of these valves are more perfect the greater the pressure exerted from above, in consequence not only of their edges, but of their pouch-like sides coming into contact.

Impulse of the heart.—The tilting forward of the cardiac apex is caused by the peculiar spiral arrangement of its contractile fibres, as clearly shewn by John Reid. These fibres, according to Pettigrew, are arranged in seven layers or strata, and their course may be readily demonstrated by forming a cone out of a sheet marked with lines, as represented Plate XI. fig. 9.

The inner surface of the heart is considerably more irritable than the outer, and the right auricle retains the power of contractility longer than any other part of the body, and has consequently been called *ultimum moriens.* The blood is the natural stimulus to this contractility, and hence why, the more blood is forced into it as the result of exercise and increased respiration, the more rapid its actions become. The heart, however, will continue to contract regularly when cut out of the body of an animal recently killed, and when deprived of blood; but then the stimulus is supplied by the air, or by the table on which it lies. Under any circumstances, the rhythmical action of its various parts is owing to the distribution of ganglionic nerves in its substance, constituting one of the excito-motory actions which will be subsequently described. The heart is also readily excited by various emotions of the mind, though not by volition; hence in ancient times it was considered the peculiar seat of the affections and passions,—an opinion which may be still traced in numerous expressions common to the phraseology of all languages even in the present day.

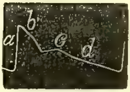
The force with which the left ventricle of the heart contracts is about double that exerted by the contraction of the right, which results from the greater thickness of its walls, and the greater resistance it has to overcome. It has been calculated that the static force with which the blood is impelled in the human aorta from the ventricle is equal to that of 4 lb. 4 oz. on the square inch, and in that of a mare is equal to 11 lb. 9 oz. The frequency of the heart's action is modified by a variety of circumstances, which we shall allude to immediately when speaking of the pulse.

Arterial Circulation.—The arteries are tubes composed of elastic and contractile fibrous tissues (p. 84), the former being most abundant in the largest vessels, where the pressure is greatest, while the latter exist almost alone, where the impulse of the heart is scarcely felt. Their functions are,—1st, The conveyance and distribution of blood to several parts of the body; 2d, The gradual conversion of the pulsatile or wave-like movements into a uniform flow; 3d, By means of their elasticity to diminish the resistance which the ventricle has to overcome. The diminution of the impulse as the arteries recede from the heart, and its ultimate extinction in the capillaries is attributable, 1st, to the gradually increasing superficies of the vascular surface; 2d, to diminishing elasticity; and, 3d, to increasing contractility as the vessels become smaller.

The most careful investigations made in modern times by Poissieulle, Valentin, and Ludwig, as to the static force of the heart and arteries, shew that it is equal to about 4 lb. on the square of inch. Assuming the internal superficies of the left ventricle to be about thirteen inches, this would give 52 lb. as the force it exerts. Now, Hales, more than a hundred years ago, calculated it to be 51½ lb., which must not only satisfy us of his accuracy as an observer, but convince us that no change has occurred in the force of the pulse, either in man or animals, during that time. The importance of this fact I shall allude to subsequently. The experiments of Marey indicate that there are two forces propelling the fluid—one, direct, dependent on the heart or pump ; the other, secondary, caused by the recoil of the distended blood tube. The intensity of the latter force, however, gradually diminishes as the wave of fluid recedes from the source of afflux, while the time of the pulse remains the same.

The pulse.—The blood nowhere passes through an artery so rapidly as it is forced into it by the left ventricle of the heart, on account of the resistance offered by all the tubes against which it is forced. The consequence is, that when it receives the wave of blood, both the diameter and length of the vessel is increased, and this is followed by a recoil and recovery of its previous position, owing to the elasticity of the tube. These operations constitute the pulse, which is felt when the finger slightly compresses an artery. The pulse differs after violent exercise, according to the time of the day and position of the body. Exercise raises the pulse. It is quicker in the morning than in the evening ; and hence, it has been supposed, why a glass of wine is more stimulating early in the day than at night. In health, the pulse reaches its maximum about noon, and its minimum towards midnight. It is more frequent in the erect than in the sitting position, and quicker then than in the recumbent posture. The difference between standing and sitting is about 10 pulsations ; between sitting and lying, 5 ; and between standing and lying, 15 pulsations ; much, however, depends on the muscular effort employed. The natural pulse in the adult male may be stated as varying between 60 and 70 pulsations in the minute ; that of the female being, on an average, about 10 beats more. In a newly-born infant, it is from 130 to 140 ; in old age, from 50 to 60. In diseases, the deviation from the healthy standard as to frequency is very remarkable. It has been known in profound coma to be only 17, and in cases of water in the brain in children it has been counted 200 in the minute. The volume or force of the pulse may also vary ; hence the terms *strong* or *weak*, *full* or *small*, *hard* or *soft*, *rigid*, *tense*, *wiry*, *thready*, &c. As regards rhythm or ime, it may be *regular*, *irregular*, *unequal*, *intermittent*, *jerking*, &c.

Many efforts have been made in recent times to render our knowledge of the pulse more accurate by means of various instruments. The *Sphygmoscope* of Scot Alison, the *Kymographion* of Ludwig, the *Sphygmosphone* of Upham, and the *Sphygmographs* of Vierordt, Czermak, and Marey, have been employed for this purpose. The Sphygmosphone of Dr Upham of Boston, U. S., enables the ear to determine the frequency and rhythm of the pulse in individuals many miles off through the ordinary electric wire. The Sphygmograph of Marey, with the modifications it has undergone, marks off waves on paper or glass, which correspond to the pulsations of an artery. The wave so marked may be divided into four parts : 1. The upward stroke, *a*, is synchronous with the ventricular contraction, and shews the amount of impulse dependent on the systole ; 2. The apex of the wave and upper portion of the descending stroke, *b*, indicates the tension of the vessel during the short pause of the heart ; 3. The second elevation in the descending stroke, *c*, is caused by the flapping together of the aortic valves, and shews the duration, amount, and rhythm of the second sound ; 4. The remainder of the descending line, *d*, is synchronous with the long pause, and is influenced by the rapidity with which the blood escapes through the capillaries. The entire tracing enables us to determine, 1st, the mode and duration of the contraction of the heart, 2d, the soundness of the arteries, and 3d, the relative quantity of blood contained in the arteries and veins, that is the balance of pressure between the venous and arterial systems. (See Practical Physiology.)



Capillary circulation.—The capillaries, as was previously remarked (p. 85), consist of delicate membranous contractile tubes, and their functions seem to be,—1st, To subdivide the blood, so that it may be brought within the attractive influence of the tissues ; and 2d, To act as fine filters, permitting an exchange of matter to be constantly carried on between the blood and the textures. In the transparent webs of certain animals, the blood may be seen passing through these tubes in a state of health with a uniform flow. There is no evidence that they exercise any influence in propelling the blood by contracting their walls, but there is every reason to suppose that the constant attraction exerted by the tissues in drawing nutritive matter from the blood must exercise a considerable power in drawing the blood onwards. We observe this in plants and animals which have no hearts or contractile vessels to propel the nutritive fluid, and we see it strongly manifested where, in consequence of excessive local growth, the blood increases in a part, as in the scalp during the annual growth of the stag's horns, in the breast during lactation, in the gums during dentition, in menstruation, and so on. In all such cases the vessels of the part are enlarged and turgid with blood, a phenomenon formerly ascribed vaguely to a "determination of blood to the part," but now known to result from the increased attractive force exercised by the tissues on the blood in places which are the seat of excessive local growth. The same theory serves to explain the phenomenon of the morbid process known as inflammation.

There can be no doubt that the arrangement and forms of plexus in the capillaries have much to do with the functions of the organs they supply. Where the plexus is dense, the circulation is more active, and rapid changes are favoured, as in the lung or liver. Where, on the other hand, the plexus is large, as in the bones, a tendency to mineral deposition is manifested. Where the vessels are formed into tufts, as in the kidney, an obstruction to the circulation is produced which favours the separation of water, &c. The character of these plexuses is at once demonstrated by successful injections, and the tissues to which they belong may be at once detected by microscopical investigation. (See various plexuses, Plate XI. figs. 10 to 15, Plate XII. figs. 3 and 4, Plate XIII. fig. 6.)

Venous circulation.—The veins arise from the capillaries, and are similar in structure to the arteries, with the exception that the elastic tissue is not so thick. It has been supposed that the forces propelling the blood through the arteries and capillaries are sufficient to cause its return to the heart through the veins, but this is assisted by internal valves and by the respiratory movements of the chest. The former are numerous, and so arranged that the blood can never return towards the capillaries. Every motion of the body and contraction of the muscles through which veins pass must—by compressing them, and thereby squeezing the blood towards the heart—assist its transit. Expiration favours the flow of blood in the arteries, and inspiration favours it in the veins, but to no great extent. It does not operate in vessels distant from the thorax.

We may consider, therefore, that the muscular force of the heart, assisted by the elasticity of the arteries propels the blood into the capillaries. Then a new force is superadded dependent on the nutritive exchanges constantly going on between the tissues and the blood, which conducts it onwards to the veins. In them the returning force is assisted by the mechanical action of valves and muscular pressure, and near the heart (though in a feeble degree), by the movements of respiration.

Rapidity of the blood.—It is very difficult to determine the rapidity of the blood in different parts of the circulation. This has been attempted, however, by means of two instruments, viz., the *Hæmatachometer* of Vierordt and the *Hæmadrometer* of Volkman. (See Practical Physiology.) According to Vierordt, it flows at the rate of 10½ inches in a second in the carotid artery, and 2½ inches in the metatarsal artery of a man. According to Volkman, it runs from 12 to 17 inches per second in the carotid artery of a horse, and 12 inches per second in the carotid of a dog. Chauveau, with a somewhat improved instrument, estimated the rapidity of the blood in the carotid of the horse at 20·28 inches per second during the systole of the heart, but only at 8·78 inches during the diastole. Lortet pointed out that the rapidity is greatest during expiration and least during inspiration, but the more recent researches of Einbrodt and Burdon Sanderson shew the reverse, viz., that during inspiration there is increased pressure on the vessels, augmented action of the heart, and more rapid flow of blood, while during expiration pressure on the vessels is diminished and the pulse falls. According to Hales, Valentin, and Weber, the blood runs at the rate of about an inch per minute in the capillaries of the frog. In warm-blooded animals, however, it is more rapid, being, according to Volkman, 1·8 inches per minute. In the veins the flow of the blood must be diminished, but to what extent has not been estimated. From watching the period occupied by poisons in passing from one part of the body to another, as in the experiments of Blake, it would appear that a portion of blood can traverse the entire circulation in the horse in half a minute.

The circulation presents peculiarities within the Cranium, in the portal and pulmonary circulations, and in the fœtus.

Peculiarity of the circulation within the Cranium.—That the circulation within the cranium is different from that in other parts of the body was first pointed out by the second Monro. It was tested experimentally by Dr Kellie of Leith, ably illustrated by Dr Abercrombie, and successfully defended by Dr John Reid. The views adopted by these distinguished men were, that the cranium forms a spherical bony case capable of resisting the atmospheric pressure, the only openings into it being the different foramina by which the vessels, nerves, and spinal cord pass. The encephalon, its membranes and blood-vessels, with perhaps a small portion of the cerebro-spinal fluid, completely fill up the interior of the cranium, so that no substance can be dislodged from it without some equivalent in bulk taking its place. Dr Monro used to point out that a jar or other vessel similar to the cranium, with unyielding walls, if filled with any substance, cannot be emptied without air or some substance taking its place. To use the illustration of Dr Watson, the contents of the cranium are like beer in a barrel, which will not flow out of one opening unless provision be made at the same time that air rushes in. The same kind of reasoning applies to the spinal canal, which, with the interior of the cranium, may be said to constitute one large cavity, incompressible by the atmospheric air.

Before proceeding further, we must draw a distinction between pressure on, and compression of, an organ. Many bodies are capable of sustaining a great amount of pressure without undergoing any sensible decrease in bulk. By compression must be understood that a substance occupies less space from the application of external force, as when we squeeze a sponge, or compress a bladder filled with air. Fluids generally are not absolutely incompressible; yet it requires the weight of one atmosphere, or 15 lb. on the square inch, to produce a diminution equal to $\frac{1}{20,000}$th part of the whole. Now, this is so exceedingly small a change upon a mass equal in bulk to the brain as not to be appreciable to our senses. Besides, the pressure on the internal surface of the blood-vessels never exceeds 10 or 12 lb. on the square inch during the most violent exertion; so that, under no possible circumstances can the contents of the cranium be diminished even the $\frac{1}{20,000}$th part. When the brain is taken out of the cranium, it may, like a sponge, be compressed by squeezing fluid out of the blood-vessels; but during life, surrounded as it is by unyielding walls, this is impossible. For let us, with Abercrombie, say that the whole quantity of blood circulating within the cranium is equal to ten,—that is, five in the veins, and five in the arteries; if one of these be increased to six, the other must be diminished to four, so that the same amount, ten, shall always be preserved. It follows, that when fluids are effused, blood extravasated, or tumours grow within the cranium, a corresponding amount of fluid must be pressed out, or of brain absorbed, from the physical impossibility of the cranium holding more matter. At the same time, it must be evident that an increased or diminished amount of pressure may be exerted *on* the brain proportioned to the power of the heart's contraction, the effect of which will be, not to alter the amount of fluids within the cranium, but to cause, using the words of Abercrombie, "a change of circulation" there, and consequently more or less general or local disturbance of function.

Dr Kellie performed numerous experiments on sheep and dogs in order to elucidate this subject. Some of these animals were bled to death by opening the carotid or femoral arteries, others by opening the jugular veins. In some the carotids were first tied, to diminish the quantity of blood sent to the brain, and the jugulars were then opened, with the view of emptying the vessels of the brain to the greatest possible extent; while in others, the jugulars were first secured, to prevent as much as possible the return of the blood from the brain, and one of the carotids was then opened. He inferred, from the whole inquiry, which was conducted with extreme care—"That we cannot, in fact, lessen to any considerable extent the quantity of blood within the cranium by arteriotomy or venesection; and that when, by profuse hæmorrhages destructive of life, we do succeed in draining the vessels within the cranium of any sensible portion of red blood, there is commonly found an equivalent to this spoliation in the increased circulation or effusion of serum, serving to maintain the plenitude of the cranum."

Dr Kellie made other experiments upon the effects of position immediately after death from strangulation or hanging. He also removed a portion of the unyielding walls of the cranium in some animals by means of a trephine, and then bled them to death ; and the differences between the appearances of the brain in these cases and in those where the cranium was entire, was very great. One of the most remarkable of these differences was its shrunk appearance in those animals in which a portion of the skull was removed, and the air allowed to gravitate upon its inner surface. He says,—"The brain was sensibly depressed below the cranium, and a space left, which was found capable of containing a teaspoonful of water." These facts have been confirmed by the more recent investigations of Kussmaul and Tenner.

When a piece of the cranium is removed from the cranium of a living animal with a trephine, the brain exhibits two kinds of movements. One of these is synchronous with the pulse, the other with expiration. The first depends upon an elevation of the entire brain by the fresh stream of blood driven into the large arteries at its base by each contraction of the left ventricle. The second depends upon the difficulty which the blood encounters in its free passage to the heart during expiration. On carefully watching these motions, it will be seen that they do not depend upon any recession of the brain from the inner wall of the cranium and its subsequent return, but consist of a slight protrusion through the opening in the walls of the cranium, and a return to its former level. It is obvious, therefore, that if there were no opening, there would be no movement. This conclusion, arrived at by John Reid from reasoning, has been demomstrated to be correct by Donders who, in his experiments on rabbits, could never perceive any movement when the opening in the cranium was firmly closed with a piece of glass, although they were evident enough when it was open. Under such circumstances, also, it may be seen that during partial asphyxia, the external surface of the brain becomes darker, as if congested ; an observation that shews the altered colour of the blood, but offers no proof that the quantity of fluid within the cranium is increased.

It results from these inquiries that there must always be the same amount of fluid within the cranium so long as it is uninjured. In morbid conditions these fluids may be blood, serum, or pus ; but in health, as blood is almost the only fluid present (the cerebro-spinal fluid being very trifling), its quantity can undergo only very slight alterations. There are many circumstances, however, which occasion local congestions in the brain, and consequently, unequal pressure on its structure, in which case another portion of its substance must contain less blood, so that the amount of the whole, as to quantity, is always preserved. These circumstances are mental emotions, hæmorrhages, effusions of serum, and morbid growths. Such congestions, or local hyperæmias, in themselves constitute morbid conditions; and nature has to a great extent provided against their occurrence under ordinary circumstances, by the tortuosity of the arteries and the cerebro-spinal fluid, described by Magendie.

Dr Burrows has brought forward several observations and experiments, which he considers opposed to the theory now advocated. His facts are perfectly correct. We have repeated his experiments on rabbits, and can confirm his descriptions. It is the inferences he draws from them that are erroneous. For the paleness that results from hæmorrhage, and the difference observable in the colour of the brain when animals immediately after death are suspended by their ears or by their heels, are explicable by the diminished number of coloured blood particles in the one case, and by their gravitation downwards in the other. That the amount of fluid within the cranium was in no way affected, is proved by the plump appearance of the brains figured by Dr Burrows, and the total absence of that shrunken appearance so well described by Dr Kellie. Neither does our observation of what occurs in asphyxia or apnœa, oppose the doctrine in question, as Dr Burrows imagines, but rather confirms it.

On the whole, whether we adopt the terms of local congestion, of change of circulation within the cranium, or of unequal pressure, our explanation of the *pathological* phenomena may be made equally correct, because each of these modes of expression implies pretty much the same thing. But if we imagine that venesection will enable us to diminish the amount of blood in the cerebral vessels, the theory points out that this is impossible, and that the effects of bleeding are explained by the influence produced on the heart, the altered pressure on the brain exercised by its diminished contractions, and the change of circulation within the cranium thereby occasioned.

Peculiarity of the portal circulation. This consists in the blood derived from the stomach and the intestinal canal, the spleen, pancreas, and gall bladder, instead of passing into the vena cava directly, first traversing the liver, and returning to the central circulation by means of the hepatic veins. According to Bernard, however, there exists five large branches, in the horse, by means of which a direct communication takes place between the vena portæ and vena cava within the liver. The vena cava, also, he says, is muscular, with striated fasiculi behind the Spigelian lobe, where these communications are to be found, and possess two large valves, so arranged as to support the column of blood above them. A similar arrangement, he says, occurs in man and in other animals. If, therefore, during absorption, the large quantity of alimentary matters from the intestine is not able to empty itself with sufficient rapidity through its ramifications in the liver, it passes through the branches described into the vena cava. They are prevented, however, from passing into the iliac veins owing to the valves of the cava, but readily find their way into the renal veins by a retrograde action. Hence why the products of digestion may often be detected in the urine before they appear in the blood of the renal artery or in that of the heart.

Peculiarity of the pulmonary circulation. This consists in *venous* blood being sent to the lungs through a tube called the pulmonary *artery*, and in *arterial* blood being returned to the heart through four *veins*, termed the pulmonary veins. (See Respiration.)

Peculiarity of the circulation in erectile tissues. The erectile tissue appears essentially to consist of a plexus of veins with varicose enlargements enclosed in a fibro-muscular envelope with trabecular partitions, the contraction of which produces the result. Muller described in the penis an arrangement of vessels coming off from the arteries which he called *arteriæ helicinæ*, with dilated extremities, which, during erection, became turgid. The correctness of this description has been much disputed. It is most probable that the phenomenon is owing to venous congestion, influenced through the vaso-motor system of nerves, assisted in the case of the penis by compression of their larger trunks by the ischio-cavernosi and bulbo-cavernosi muscles.

Peculiarity of the fœtal circulation.—In the mature fœtus, the fluid brought from the placenta by the umbilical vein (Plate IX. fig. 16, 3), is partly conveyed at once to the vena cava ascendens, by means of the ductus venosus (5), and partly lows through two trunks (4, 4) that unite with the portal vein 7), returning the blood from the intestines, into the substance f the liver, thence to be returned to the vena cava by the epatic vein. Having thus been transmitted through the two reat depurating organs, the placenta and the liver, the blood hat enters the vena cava is purely arterial in its character ; but, eing mixed in the vessels with the venous blood that is reurned from the trunk and lower extremities, it loses this charcter in some degree by the time that it reaches the heart. In he right auricle, which it then enters, it would also be mixed ith the venous blood which is brought down from the head nd upper extremities by the descending cava, were it not that provision exists to impede (if it does not entirely prevent) any urther admixture. This consists in the arrangement of the ustachian valve, which directs the *arterial* current (that flows pwards through the ascending cava) into the *left* side of the eart, through the foramen ovale, whilst it directs the *venous* urrent (that is being returned by the descending cava) into he *right* ventricle. When the ventricles contract, the arterial lood contained in the left is propelled into the ascending orta, and supplies the branches that proceed to the head and pper extremities before it undergoes any further admixture ; hilst the venous blood contained in the right ventricle is rced into the pulmonary artery, and thence through the uctus arteriosus (17), which is like a continuation of its trunk, nto the descending aorta, mingling with the arterial currents hich that vessel previously conveyed, and thus supplying the runk and lower extremities with a mixed fluid. A portion of his is conveyed, by the umbilical arteries, to the placenta, in hich it undergoes the renovating influence of the maternal lood, and from which it is returned in a state of purity.

In consequence of this arrangement, the head and superior exremities are supplied with pure blood returning from the placenta, hilst the rest of the body receives blood which is partly venous. his is probably the explanation of the fact, that the head and pper extremities are most developed, and from their weight ccupy the inferior position in the uterus. At birth the course f the circulation undergoes changes. As soon as the lungs are istended by the first inspiration, a portion of the blood of the ulmonary artery is diverted into them, and there undergoes eration ; and as this portion increases with the full activity of the lungs, the ductus arteriosus gradually shrinks, and its cavity finally becomes obliterated. At the same time, the foramen ovale is closed by a valvular fold, and thus the direct communication between the two auricles is cut off. When these changes have been accomplished, the circulation, which was before carried on upon the plan of that of the higher reptiles, becomes that of the complete warm-blooded animal; all the blood which has been returned in a venous state to the right side of the heart being transmitted through the lungs before it can reach the left side, or be propelled from its arterial trunks.

RESPIRATION.

The great object of this function is to admit into the system oxygen derived from the atmospheric air, and to excrete carbonic acid gas and watery vapour. It is carried on by means of lungs, the structure of which organs is so arranged as to expose a large surface, covered with capillary blood-vessels, to the action of the atmosphere.

Structure of the lungs.—The spongy texture of the lung is formed by the sudden expansion of the terminal bronchial tubes into air vesicles, which, according to Kölliker, takes place in man as represented Plate XII. fig. 5; but which, according to Dr Waters of Liverpool, gives rise to from two to seven or eight elongated air vesicles (Fig. 6). These consist of delicate membranous walls, lined internally by pavement epithelium (Fig. 4, c), which readily allow gases to pass through them. Viewed externally under a low power, these compressed air vesicles present the appearance represented Plate XII. fig. 1; but on section, look like fig. 2. A thin slice, magnified 200 diam. linear, shews the air vesicles cut across, Fig. 4, *b*, *b*, *b;* the fibrous stroma between them, *a;* and the rich plexus of blood-vessels, ramifying outside and around them, *d*, *d*. The extreme vascularity of the organ may also be judged of by examining a well injected preparation of pulmonary tissue under a low power, as in Plate XI. fig. 13. In the bird, as was shewn by Mr Rainey, this vascular plexus forms a dense thick layer of minute capillaries surrounding the air vesicles, as shewn Plate XII. fig. 3. In frogs and ophidian reptiles, the lungs consist of two bags or bladders having depressions and elevations on their internal surface,—an arrangement which in them and the higher animals permits of an extended surface, through which gases readily pass into the dense plexus of vessels surrounding them, and mingle with the blood.

Mechanism of respiration.—This consists of two acts—dilatation and contraction of the chest, or *inspiration* and *expiration.* The dilatation of the chest during ordinary respiration is principally owing to the contraction and descent of the diaphragm muscle. But when a deep breath is taken, the cavity of the chest is still further dilated by the *intercostales*, *scaleni*, *serrati*, and other muscles. Expiration ordinarily is owing to the elasticity of the lungs and walls of the chest, aided by the contractions of the abdominal muscles. During forced expiration, the *longissimus dorsi*, *sacro-lumbales*, and other muscles, co-operate.

The manner in which oxygen is absorbed, and carbonic acid given off, is the result of physical laws. The air introduced by atmospheric pressure, brought into play by the action by the diaphragm and other respiratory muscles, fills the nasal passages, the trachea, and larger ramifications of the bronchi. This, however, would not penetrate to the minute tubes and air vesicles of birds and mammals, though it would operate perfectly in the saccular lungs of reptiles. The lower or residual portion of air, therefore, would never be removed, were it not for the readiness with which gases mingle together. Oxygen also, being lighter than carbonic acid gas, would not descend to the lower parts of the lung, if the physical law of diffusion established by Graham did not come into operation—viz., that gases are diffused inversely in proportion to the square roots of their densities. Consequently the descending amount of oxygen will exceed that of carbonic acid gas in the proportion of 4– square root of 16– the density of oxygen, to 4·69– the square root of 22– the density of carbonic acid. Hence is explained how, notwithstanding the small quantity of fresh air received into the lungs at each inspiration, that quantity is diffused rapidly throughout the whole texture.

Auscultation.—If a stethoscope be placed over the larynx and trachea of a healthy man, two noises will be heard—one accompanying the act of inspiration, and the other that of expiration. These are called the *laryngeal and tracheal sounds or murmurs.* If it be placed a little to the right or to the left of the manubrium of the sternum, there will be heard the same sounds diminished in intensity. These are the *bronchial sounds or murmurs.* If now we listen under and outside the nipple on the right side, or posteriorly over the inferior lobe of either lung, there will be heard two very fine murmurs. That accompanying the inspiration is much more distinct than that accompanying the expiration, which has been attributed by Dr Salter to the current of air striking against the angles of divisions of the bronchi, and by Dr Waters to the slight constriction that exists at the mouth of each air sac. By some, on account of its excessive fineness, it is stated that there is no expiratory murmur in health ; but this is incorrect. These sounds, then, are the *vesicular respiratory murmurs.* All these sounds become exaggerated during forced respiration, but in a state of health they never lose their soft character. Again, if we listen in the same places whilst the individual speaks, there will be heard a peculiar resonance of the voice, which has been called, in the first situation, *pectoriloquy;* in the second, *bronchophony;* while in the third it is scarcely audible. A knowledge of these circumstances, and a capability of appreciating these sounds, are necessary preliminary steps to the right comprehension and detection of the murmurs which may be heard during disease. These respiratory murmurs are occasioned by the vibration of the tubes through which the air rushes, according to well known acoustic principles. Hence they are loudest in the trachea, finer in the large bronchi, and finest in their ultimate ramifications. The vocal resonance, on the other hand, originates in the larynx ; and diminishes or increases—1st, According to the distance of any point from the source of the sound ; and, 2d, According to the power which the textures have in propagating it. The changes produced in these murmurs by disease belong to the study of Clinical Medicine.*

Number and extent of respirations.—The number of respirations which occur in the minute during health are from fourteen to eighteen ; but in disease they have been known to be so low as seven, and so high as a hundred. The amount of air inspired also varies ; in health ranging from 20 to 25 cubic inches (Coathupe). A man's average breathing capacity is best tested by a forcible expiration, which yields, according to Hutchinson, 225 cubic inches, as measured by the spirometer, and exercises a pressure equal to a ½ lb. upon each square inch of surface, or 150 lbs. for the male, and 123½ lbs. for the female.

The ordinary amount of air taken in is called by Mr Hutchinson *breathing* or *tidal* air, from 20 to 25 cubic inches. The extra amount which may be inspired forcibly he calls *complemental* air, about 100 cubic inches more. What remains after an ordinary inspiration he calls *reserve* air, about 100 cubic inches; but as it is impossible by the greatest efforts entirely to free the lung of air altogether, he denominates that portion which no power can expel *residual* air, also about 100 cubic inches. The total amount of air then in the chest, after the deepest possible inspiration, amounts to about 325 cubic inches. With the spirometer he measured the alterations which take place in the average breathing capacity according to the weight and age of the individual, and estimated the force employed by the muscles of inspiration, which, in a man capable of breathing 200 cubic feet of air, he fixed at 301 lbs.

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* See the Author's Clinical Medicine, 5th edition, p. 67.

Marey and others have invented instruments by which the movements of respiration and the quantity of air can be registered. That constructed by MM. Bergeor and Kastus is figured Plate XXI. fig. 22. (See Practical Physiology.)

Effect of respiration on the atmospheric air. The great change which the atmospheric air undergoes in going into and coming out of the lungs, is the removal of a portion of the oxygen, and the substitution of a quantity of carbonic acid gas. For a long time it was supposed that the loss of the one was exactly equal to the production of the other, but it is now known that the volume of oxygen which is absorbed is far greater than that of the carbonic acid given off; and hence we must conclude that the former gas serves not only for the oxidation of carbon, but also of hydrogen in the animal organism. If the air be already charged in some degree with carbonic acid gas, the quantity exhaled is much less, a circumstance which strongly points out the necessity of ventilation. It is not sufficient for health that a room should contain the quantity of air requisite for the respiration of its inhabitants during a given time, since long before its exhaustion it will contain a quantity of carbonic acid sufficient to interfere with the necessary excretion from the blood. Hence the headache and other symptoms often experienced in breathing confined air. The manner in which oxygen is diffused through the air vesicles, and carbonic acid given off from them, seems owing to the physical law described by Professor Graham with respect to diffusion of gases; and the quantity of the former which enters will be much greater than that of the latter, which passes out in the proportion of 1174 to 1000 The one-sixth of oxygen which thus enter the body, and is not converted into carbonic acid, is supposed to combine with hydrogen, furnished by the food and by the disintegration of the tissues, to produce water. Part of the water so formed is again exhaled in the form of vapour from the lungs. Another part of the oxygen is used in oxidising the sulphur and phosphorus taken in with the food, and excreted chiefly in the condition of sulphuric and phosphoric acids. The absolute quantity of solid carbon given off by the lungs is about 160 grains per hour, or 8 oz. troy in the twenty-four hours. This varies, however, according to various circumstances, especially exercise and food. During hard labour 12 ounces, and during the repose of sleep only 4 ounces, may be excreted.

The most important experiments in recent times as to the excretion of carbonic acid by the lungs, have been made by Dr E. Smith of London.* In determining the influence of food, he made numerous careful experiments ; and of the many conclusions he arrived at on this subject, the following may be quoted: 1. That the influence of food is evident soon after its introduction into the system, and attains its maximum within about two hours. 2. Pure starch and fat do not increase the quantity of carbonic acid evolved, but on the contrary, the latter somewhat lessens it. 3. The cereals, however, which contain, besides starch, albuminous products, gluten and sugar, increase the excretion of carbonic acid to the extent of two grains per minute. 4. Milk, sugar, tea, and coffee do the same. 5. Alcohol, rum, and malt liquors increase it to the extent of one grain per minute ; but brandy and gin, especially the latter, lessen it. 6. Foods may be classified into non-excitants and excitants as regards the excretion of carbonic acid gas. The *non-excitants* are, starch, fat, some alcohols, and coffee berries. The *excitants* are, sugar, milk, cereals, potatoes, gluten, gelatin, fibrin, albumin, tea, coffee, cocoa, chicory, alcohol, rum, and some wines.

These results are remarkable as distinguishing starch and fat as non-excitors of increased carbonic acid in expiration, thus confirming what I have long maintained on histological grounds —viz., that fats and oils serve largely to build up the tissues, and are not, as Liebig endeavoured to shew, merely respiratory food. They are further remarkable in shewing that alcohol and rum increase, while brandy and gin diminish, the carbonic acid—effects, which, if correct, are wholly inexplicable.

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* Trans. of Royal Society, London, 1859.

In addition to the amount of exercise and the nature of food, the quantity of carbonic acid excreted by the lungs varies according, 1st, to *age*—it is greater in adults than in childhood and advanced age ; 2d, to *sex*—it is greater in males than in females, and in the latter is increased by suppression of the menses and by pregnancy ; 3rd, to *external temperature*—it is greater in cold than in warm weather ; 4th, to *season*—it is greater in spring than in autumn ; 5th, *period of the day*—it is less by night than by day ; 6th, *development of the body*—it is greater in robust than in feeble persons ; 7th, to *sleep or watchfulness*—in sleep it is less than during the waking state ; and 8th, according to *diseased conditions* which have not yet been very carefully determined.

During respiration, an absorption and exhalation of the nitrogen of the atmosphere is constantly taking place, but the amount of the one balances that of the other.

The skin, also, is continually giving off a small quantity of carbonic acid gas, the amount of which, however, has not been very accurately estimated. It is said to be from 1.30th to 1.60th of that exhaled from the lungs (Scharling). According to Dr E. Smith, it amounted in summer to 6 grains per hour, or about 1 per cent. of the amount passing off by the lungs.

The amount of watery vapour given off by the lungs is sufficient to saturate the expired air, or nearly so, and the quantity of water varies from 6 to 27 ounces daily, according to the nature of the diet, amount of exercise, temperature, humidity of the atmosphere, &c., &c.

Effect of respiration on the blood.—As regards the effects of respiration on the blood, the most striking is the change of colour of the claret-like venous into the bright scarlet of arterial blood. Venous blood out of the body, when exposed to the atmosphere, undergoes the same change. In the lung there are greater facilities for accomplishing this than on blood drawn from a vessel, on account of its minute division into small streams ; while the delicate membrane lining the air vesicles, from the rapidity with which gases are diffused through them, may be said to offer no obstruction whatever to this process. The oxygen which enters the lungs also colours the free nuclei in mammals, and the cells in the other vertebrata which join the blood from the chyliferous system. The temperature of arterial blood is one or two degrees higher than venous blood (Davy). The specific gravity and number of corpuscles also are said to be somewhat greater, and it contains a larger amount of oxygen and less carbonic acid. Recent researches have shewn that the power of absorption of the blood for oxygen and carbonic acid gas is altogether peculiar, and follows laws of its own. Thus at 32° F. it will absorb from 16·882 to 19·794 volumes of oxygen, whilst the same amount of water will only absorb 2·97 vols. (Setschenow).* At 48° F. it will absorb 178·3 vols. of carbonic acid, while the same amount of water will absorb only 100 vols. (Meyer).† This must be dependent, more or less, on chemical affinity. Thus the oxygen is supposed to unite with the hæmoglobin of the red corpuscles, and the carbonic acid with the carbonate and alkaline phosphate of soda dissolved in the liquor sanguinis. It is now determined that these gases may not only exist free in the blood, as shewn by Magnus, but also in combination. The proportion of the gases in human blood, according to Setschenow, is in 100 vols. :—

Total quantity of gas in the blood .	48·20
Total free gas	45·88
Oxygen	16·41
Free Carbonic Acid . . .	28·27
Combined Carbonic Acid . . .	2·32
Nitrogen	1·20

These proportions vary in different parts of the arterial and venous systems, according to periods of digestion, of exercise, and of other causes ; but further observations are required to determine the amount of difference.

Numerous chemical theories have been advanced to explain the manner in which oxygen is removed from the inspired air, and a quantity of carbonic acid gas added to expired air. But whether the oxygen, after forming an acid, unites with the alkalies,—whether it attaches itself exclusively to the colouring matter of the corpuscles or to the fibrin, or unites with phosphorus and fatty matter, are points not yet finally determined.*

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* Beiträge zur Pneumatologie des Blutes. Zitzungsbericht d. k. Akad. d. Wissens., xxxvi., 1859, p. 293.

† Zeitschrift f. Rat. Med. Bd. 8, p. 256.

With regard to the respirability of various gases, pure *carbonic acid gas* cannot be inhaled on account of its causing spasm of the glottis. Experiments on the inhalation of *nitrogen* have led to no results ; it seems to be inert so long as oxygen is not excluded. Excess of *hydrogen* in the atmosphere may be breathed for a length of time, provided oxygen be present. *Nitrous oxide gas*, or an excess of oxygen, as is well known, acts as a powerful stimulant. A small portion of *carbonic oxide gas* with air causes a sensation of tightness, suffocation, insensibility, and death. *Sulphuretted hydrogen*, *selenuretted hydrogen*, *phosphuretted hydrogen*, and *arsenuretted hydrogen*, *ammoniacal gas*, *sulphurous acid*, and *chlorine* produce similar effects.

Asphyxia.—If respiration be embarrassed or difficult, it constitutes *dyspnœa ;* if arrested, from exclusion of atmospheric air, *asphyxia* is produced. As a general rule, if the air be cut off from the lungs of a warm-blooded animal by strangulation or immersion in water, all external muscular movements will cease in a period varying from three to five minutes, and the circulation comes to a stop in ten minutes. In experiments performed by a Committee of the Medico-Chirurgical Society of London, it was ascertained that when death by drowning took place very rapidly, it was in consequence of water entering the lungs. But if a cork was inserted firmly into a tube previously tied into the trachea to prevent this, efforts to breathe continued for 4 min. 5 sec. in dogs, and 3 min. 25 sec. in rabbits. Some individuals, by force of habit, seem to have acquired the power of retaining their consciousness for a considerable time under water, as in the divers of Ceylon, some of whom have been known to remain immersed, and actively picking up oysters, three or four minutes. This period, under ordinary circumstances, is sufficient to induce death ; for few persons recover who have been under water four minutes. Exceptional instances, indeed, are on record where persons have revived after a submersion of half-an-hour. It is supposed, however, that in these a state of syncope was occasioned at the moment of immersion, from fear, mental emotion, or concussion of the brain, so that in them respiration did not exist in its full activity. Newly-born animals can survive immersion in water much longer than adults ; and the lower the temperature, the less rapid is asphyxia.

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* See Article Respiration, by Reid, for various theories of this process. Cyclop. of Anatomy and Physiology. Also Article, Respiration, by Dr Michael Foster, in "Watt's Dictionary of Chemistry."

The order in which the vital functions are arrested from asphyxia, according to J. Reid, are as follows : " Dark blood is at first transmitted freely through the lungs, and reaches the left side of the heart, by which it is driven through all the textures of the body. As the blood becomes more venous, its circulation through the vessels of the brain deranges the sensorial function, and rapidly suspends them, so that the individual becomes unconscious of all external impressions. The functions of the medulla oblongata are enfeebled about the same period that the sensorial functions are arrested, but are not fairly suspended for some time longer. Immediately after the sensorial functions are suspended, and the blood has become still more venous, it is transmitted with difficulty through the capillaries of the lungs, and consequently begins to collect in the right side of the heart. A similar quantity of blood must now necessarily leave the left side of the heart, and this diminution of the quantity of blood sent along the arteries, conjointly with its venous character and the ultimate arrestment of the circulation, being circumstances incompatible with the manifestation of vitality in the other textures of the body, general death is sooner or later induced."

To restore asphyxiated persons, no time should be lost. The individual should be immediately placed on the abdomen, to allow of the tongue falling forwards, and any fluid in the mouth to escape. One of the arms should be put below the forehead, to prevent the possibility of the nose and mouth being compressed by the ground. The body should then be alternately rolled on the side, and again placed on the abdomen, so as to imitate the compression and expansion of the chest in respiration. The extremities should be assiduously rubbed, especially pressing upwards, and warmth applied. This is the method recommended by Dr Marshall Hall. According to Dr Silvester, however, artificial respiration is best carried on by placing the body on the back, and alternately raising and depressing both arms. To renew the heart's actions, Dr J. Reid recommended bleeding from the jugular vein, and encouraging the flow of blood from the lower orifice alone, taking care, of course, to prevent the entrance of air. In this way only can the right cavities of the organs be relieved of the mass of blood which mechanically distends them and prevents their contraction.

Ventilation.—From an account of the respiratory process now given, it will be seen that a very small amount of poisonous material in the atmosphere produces a powerful influence on the blood, and therefore on the health of an individual. 10,000 volumes of pure air contain only from 2 to 5 of carbonic acid; but in rooms more or less crowded the air has been ascertained to contain from 1 to 7 in 1000 volumes. Should there be only from 1½ to 3 volumes in that quantity, headache and vertigo are generally experienced; and if it increase to 20 volumes in 1000, it causes coma and asphyxia. An adult man inspires and expires during tranquil respiration 30 cubic inches of air every respiration; and if he breathes 16 times per minute, he requires 480 cubic inches per minute, or 28,800 cubic inches per hour. If pure air inspired contain 4 volumes of carbonic acid in 10,000, while expired air contain 40 volumes in 1000, in addition to organic matter and watery vapour, 12 to 19 cubic feet of carbonic acid are expired in 24 hours. To dilute, therefore, the expired air, so that the carbonic acid shall be reduced to its normal standard—that is, 4 in 10,000—there will be required 1666 cubic feet of pure air per hour. But as the air added, itself contains some carbonic acid, and as the exhalation from the skin also requires dilution, it may be said that 2082 cubic feet of fresh air are required every hour.

In certain diseases, more especially typhous fever, scarlatina, measles, &c., a subtile organic matter is evolved from the body which taints the atmosphere, whereby they are propagated. The amount of pure air required to neutralise such noxious emanations has been variously estimated. Some imagine that a perceptible smell gives indication of such noxious matters, and Grassi mentions that in the Neckar Hospital 3500 cubic feet of pure air per head did not remove such smell. This doctrine, however, is very dangerous, as many noxious gases have no smell, while many putrid and offensive odours to the nostrils have been proved to be quite innocent. Dr Sutherland believes that 4500 cubic feet per head are necessary for surgical wards, and that this should be increased to 6000 feet per head in time of epidemics. Great uncertainty exists on this point, the whole subject of ventilation having been greatly neglected. It is only now commencing to form one of the recognised important problems that demand attention among the sanatory questions of the day.

GROWTH AND SECRETION.

We have previously shewn that the tissues have a vital property of attraction and selection—by some termed *elective affinity*—whereby the necessary materials are drawn through the delicate membranous walls of the capillaries, and transformed chemically and structurally into the textures. Thus every atom of the living body has been consolidated out of materials derived from the liquor sanguinis. We are forced to adopt this theory, for it can easily be shewn that all the tissues depend on one fluid—the blood—for their nourishment; whilst it is also clear that this same fluid, in different tissues and organs, gives rise to different chemical and structural results. In this manner, an animal is maintained for a series of years with the same physical characters, the different proportions between the supply and loss causing the rapid growth of the young, the stationary period of adult life, and the decline of age. Of the ultimate causes of the different variations in growth we know nothing further than they must depend upon powers inherent in the ultimate molecules of the tissues. All that science can accomplish is to obtain a knowledge of the conditions on which it depends. Of some of these we have spoken when describing the cell theory (see p. 58), but there are four others to which we shall allude in this place.

1. *A healthy quality of the blood* is necessary for a healthy formation of texture; and this implies that all the processes of nutrition should be properly performed, including digestion, assimilation, respiration, secretion, excretion, and so on. Any one of these being disturbed, growth of the body, in whole or in part, may be faulty from want of appropriate material. The blood, however, enjoys to a certain extent the power of spontaneously correcting its own deteriorations; and if these be not excessive or too long continued, it rapidly separates or gets rid of them by means of some apparatus, and its normal characters are restored. We are continually meeting with these occurrences during our observation of disease; and in this way we account for and see the use of occasional diaphoresis, diarrhœa

epistaxis, loaded urine, and so on. It is also posssible that the excretion of one substance is more or less connected with the formation of another, as in the instances of what Mr Paget calls *complemental* nutrition, of which the growth of the beard in man and of the mammæ in females at the period of puberty are illustrations. That the quality of the blood is of the utmost importance in nutrition, is further shewn by the occurrence of those diseases which unquestionably originate in that fluid, as in the inoculation of small-pox, the exanthemata, &c. These, in their turn, appear to pass out of the system by the formation of new growths, such as the pus cells in the pustules of small-pox, the new epidermis, in scarlatina, &c.,—a process named by Dr W. Addison *cell therapeutics.*

2. *A proper quantity of blood in a part* is also essential for growth, as is proved by the effects of those occurrences which, by destroying or injuring the principal vessel leading to it, causes its wasting or death. It is also observable, that whenever parts are actively growing, they attract more blood to them than usual, shewing that there is an intimate relation between activity of formation and the quantity of blood in the textures.

3. *A certain influence of the nervous system* is so blended and mingled with nutrition of parts in the higher animals, that the impairment of the one materially interferes with the advancement of the other. Thus there is scarcely an organ in the body the functions of which may not be more or less deranged by various conditions of the mind. Hope and confidence are highly favourable to the resolution of numerous diseases; while fear and a foreboding of evil seldom fail to aggravate the most simple maladies, and in dangerous ones often render them fatal. Destruction of a nerve leading to a part not only may cause wasting of the tissue, but often ulceration and destruction of it. The same occurs when disease attacks the spinal cord, or one of the great ganglia of the sympathetic system.

4. *A healthy state of the part to be nourished* is as necessary for growth as the other conditions mentioned. If the property of attracting and selecting materials from the blood be inherent in the textures themselves, as we have seen is probable, it follows that, if these textures be seriously altered or destroyed, the property will also be altered or destroyed. Now, this is what really takes place; and hence why so many diseases of

texture, once occasioned, are kept up in spite of all the interference of art. Such is the reason, also, that blows and other injuries, by exciting or diminishing the vital properties of the textures, give rise to what are called inflammations, tumours, and other forms of so-called morbid growths.

Such are the conditions which serve to regulate growth in the animal economy. The process may be in excess or diminution, constituting what is called *hypertrophy* and *atrophy*. There is one modification of growth, however, which we must refer to especially, and which has long been known under the name of *secretion*.

Secretion.—This process was for a long time considered as one opposed to growth ; that is, as a function having for its object to separate matters from, while growth was directed to storing up or adding them to, the organism. We now know that secretion is simply a form of growth, and is carried on under the influence of the same laws which regulate the development, maturation, and decline of nucleated cells in general, and of the conditions just referred to in particular. Under the head of "Cell Tissues" we have alluded to the peculiar properties of secreting cells. They are generally formed on one side of a basement membrane, while on the other side blood-vessels are distributed, from which their contents are derived. The variations in glands simply result from the convolutions and greater or less complexity of these universal gland elements (Plate XII. figs. 7 to 11). No relation apparently exists between the structure of the glandular apparatus, or the nerves supplying it, and the secretion it pours forth. Thus the pancreas, the lachrymal and mammary glands, are very much alike in their histological elements, although the pancreatic and lachrymal fluids and milk are widely different. This fact is sufficient to convince us that a property of a peculiar kind, essentially vital, must reside in the cells themselves, which occasions these results. This property is influenced by the same causes which govern cell growth generally (p. 58) ; more especially, however, by (1) an increased or diminished flow of blood in the gland, (2) a greater or less amount in the blood of the particular matter to be secreted or separated, and (3) the influence of the nervous system. (See Excito-secretory Function of the Ganglionic System of Nerves.)

ABSORPTION AND THE SECONDARY DIGESTION.

While, on the one hand, matters are always passing from the blood to build up the tissues, on the other, matters are continually passing into the blood from those tissues which have fulfilled their appointed functions. The new material takes exactly the place and form of the old ; so that the general configuration of the body is preserved, while continually and imperceptibly undergoing a change. Although in adult animals we cannot see the tissues forming, in the embryo we can, and are consequently enabled to infer the steps of the process. But we cannot see the healthy tissues disintegrating and absorbing, even in the embryo ; and this source of information is therefore cut off from us. Almost all that we know of this process, from actual observation, is derived from the study of morbid anatomy. From this we learn that new formations such as pus and cancer cells, break down and are reduced to a fluid state in the inverse order to that in which they were developed. Thus a fluid exudation is poured out from the vessels. It coagulates in the form of molecules and granules. These unite to form nuclei, around which cell-walls are produced. If this be their ultimate point of development, they are again reduced to the fluid state, first by the solution of the cell-wall, and subsequently by that of the nucleus. The whole now again presents a molecular and granular aspect, whilst the fluid portions pass through the walls of the blood-vessels from without inwards, and so enter the circulation. Thus, all that has become solid is again reduced to a liquid or gaseous form, to pass into the blood. This is *absorption.* We do not see this process in health, but doubtless particle after particle of solid matter is reduced to fluid, and disappears, in order to give place to new particles, which for a time become solid, assume form, fulfil their function and allotted period of life, and then dissolve, are absorbed and excreted as their predecessors were before them.

This is the *secondary digestion.* Thus the blood receives matter from two sources—the primary and secondary digestions ; and is continually giving off matter in two directions—one to build up the tissues and form the secretions, the other to produce the excretions.

Chemical constitution of the blood.—Numerous analyses have been made of this fluid by the most distinguished chemists, and yet no two of them have been alike. This is explained by the fact that the chemical constitution of blood must constantly be undergoing changes, not only in various individuals, but in the some individual, from differences in diet, assimilation, respiration, excretion, exercise, and the numerous circumstances which influence the animal economy. It also varies in the two sexes. We give the results arrived at, from a large number of data, by Becquerel and Rodier :—

Table, shewing the Maxima, Minima, and Average Numbers of the Different Constituents in 1000 parts of the Blood of Man :—

	Mean.	Maxima.	Minima.
Density of defibrinated blood	1060·2	1062·0	1058·0
Density of serum . .	1028·0	1030·0	1027·0
Water	779·0	800·0	760·0
Blood corpuscles . . .	141·1	152·0	131·0
Albumin	69·4	73·0	62·0
Fibrin	2·2	3·5	1·5
Extractive matters and free salts	6·8	8·0	5·0
Fatty matters . . .	1·600	3·255	1·000
Serolin	·020	·080	impond.
Phosphorized fat . .	·488	1·000	·270
Cholesterin	·088	·175	·030
Saponified fat . . .	1·004	2·000	·700
From 1000 parts of blood, after calcination, they obtained—			
Chloride of sodium . .	3·1	4·2	2·3
Other soluble salts . .	2·5	3·2	2·0
Phosphates . . .	·334	·7	·225
Iron	·565	·633	·508

We may say that the chemical composition of the blood in a general way is as follows :—1st, The great bulk of the blood is made up of water, varying in a healthy state from 760 to 800 parts in 1000 ; 2d, The fibrin is small in quantity, varying from ½ to 3 parts ; 3d, The amount of albumen ranges between 60 and 70 parts ; 4th, The blood corpuscles vary from 130 to 150 parts ; 5th, The extractive matters and fat range from 1 to 4 parts ; and 6th, The saline matters range from 5 to 10 parts. These are not the exact proportions, but approximative results derived from numerous analyses which are easily retained by the mind.

The mean amount of the blood in the human adult male is 34½ lb., and in the female, 26 lb. (Valentin.)

The liquor sanguinis and its coagulation.—The liquor sanguinis is a slightly viscous yellow fluid, in which the blood corpuscles swim. In it the property of coagulation possessed by the blood resides, which is caused by the separation of the fibrin it held in solution. This may be *seen* under the microscope, in favourable cases, to be precipitated in the form of molecular fibres, which, entangling the corpuscles together in a mass, so form the clot of the blood. In normal blood the coloured corpuscles are equally diffused through the mass; but whenever coagulation is delayed they have more time to sink towards the bottom of the vessel, leaving a whitish layer above, which is the buffy coat. Dr Richardson endeavoured to shew that coagulation depended on the escape of a small quantity of free ammonia which exists in blood. But numerous researches, especially those of Lister and Brücke, have proved this theory to be untenable. In 1845, Dr Andrew Buchanan of Glasgow, discovered that various organic liquids that did not coagulate spontaneously, on the addition of a piece of flesh, membrane, or fluid of the clot, and other substances, did so rapidly. Schmidt attempts to explain this by supposing that coagulation depends on two substances, which he denominates *fibrino-plastic and fibrinogen.* These may exist together, or may be separate in various liquid or substances, but it is their union under certain physical conditions which, according to him, forms fibrin and causes coagulation.* In addition to fibrin, the liquor sanguinis holds in solution albumin, fat, and salts, and all those substances which are necessary, directly or indirectly, for the formation of the tissues and secretions. It may be regarded as the most elaborated portion of the blood, inasmuch as the corpuscles are dissolved in it; and, as previously stated, it receives the results both of the primary and secondary digestions. So prepared, it is the essential material or nourishing fluid, which, attracted through the capillaries by the tissues, is the foundation for all the formative processes of the economy.

Function of the blood.—The blood circulating through the body may be regarded as a river flowing by numerous canals through a populous city, which not only supplies the wants of its inhabitants, but conveys from them all the impurities which through various channels find their way into its stream. The chief supplies enter the circulation, as we have previously seen, in the form of water, albumin, and of blood corpuscles from the primary digestion. These receive oxygen in the lungs, where they become coloured, are sent all over the body, and in the ultimate capillaries yield up their oxygen, which combines with carbon and other chemical constituents of the tissues to form numerous combinations. After a time, they are dissolved in the liquor sanguinis, which fluid they serve to elaborate. The blood also receives and holds in solution the products of the secondary digestion, so that it is a highly elaborated, viscous, and complex organic liquid. It is the blastema from which the living molecules, nuclei, cells, and other elements of the tissues are continually attracting, on the one hand, new matter to supply the place of what is lost; while, on the other, it is constantly absorbing old matter which has sufficiently served the purposes of the frame. In what manner this important fluid utilises the various products it receives from both sources is as yet unknown. All that we can determine is, that the whole is in incessant motion, rushing rapidly out from the heart through the arteries, divided into minute streams by capillaries in the tissues, returning more slowly by the veins—a circuit through the frame completed in half-a-minute—subjected to the constant collision of about two billions of semi-solid corpuscles, incessantly undergoing chemical alterations when exposed to the peculiar action of every organ in the body ; and while imparting one or more of its constituent principles in this or that tissue as it passes through it, at the same time absorbing those which have been worn out in the service of the economy. Blood, therefore, is the mixture of the histogenetic and histolytic processes of the body. It is in the circulation they mingle together, and it is there consequently we must look for an explanation of numerous morbid conditions which derangements in so nicely-balanced an organic fluid may be expected to produce.

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* Archiv. für Anat. u. Physiol. 1861, p. 545, and 1862, p. 428.

Morbid conditions of the blood.—I need not dwell upon the vast importance which from the earliest times has been attached to alterations in the blood as a cause of disease. The red, white, yellow, and black bloods of Hippocrates—the acid and alkaline blood of Van Helmont—the *error loci* among the blood corpuscles of Bœrhaave—and the sthenic and asthenic states of the constitution contended for by Brown and Broussais—have each in turn regulated the medical practice of civilised nations.

In recent times, most laborious efforts have been made by means of chemical researches and of the microscope to investigate the exact condition of the blood in disease.

Chemical alterations of the blood in disease.—The most elaborate investigations into this subject have been made by the French chemists and pathologists, more especially by Andral and Gavarret, in 1840, and by Becquerel and Rodier, in 1844, whose researches have for the most part been confirmed by subsequent investigators. The results which the latter chemists arrived at are as follows :—1st. Venesection greatly diminishes the number of the blood corpuscles, increases the amount of water, slightly diminishes the albumin, but in no way affects the fibrin, extractive matters, or salts. 2d. That plethora is a simple increase of all the constituents of the blood. 3d. That anæmia is in truth a misnomer, but is used in the sense of a diminished number of the corpuscles, or spanæmia. 4th. That inflammation increases the amount of the fibrin from 3 to 10 in 1000 parts, doubles the quantity of cholesterin, and diminishes the albumin. 5th. That the fibrin is diminished in fevers, exanthematous disorders, intoxication, starvation, and purpura hæmorrhagica. 6th. When any secretion is checked, its essential principles accumulate in the blood. 7th. The albumin of the blood is diminished in Bright's disease, in cardiac dropsy, and in puerperal fever.

These conclusions, founded on a large number of data, are most important, and, as we shall subsequently see, while opposed to former views of medical practice, especially in acute inflammatory diseases, completely harmonise with the results of modern experience.

Structural alterations of the blood in disease.—These for the most part have been previously described when speaking of the blood corpuscles (p. 63), and of Leucocythæmia (p. 208).

Softening and breaking up of blood coagula.—Another important discovery which greatly advanced our knowledge of the pathology of the blood was made by Mr Gulliver, who demonstrated that fluids exactly resembling pus to the naked eye were the result of mechanical softening of the clot, and that this could be determined by the microscope. As the result of numerous experiments and observations, he stated, in 1839,*—"1st. That coagulated fibrin when removed from the body and subjected to a blood heat, commences to soften in about forty hours, assuming the colour and consistency of pus, but easily distinguishable from it by microscopical and chemical examination. 2d. That the purulent-like fluid found in the fibrinous clots of the heart and arteries, and so frequently in the veins, is essentially distinct from pus, and analogous to, if not identical with, softened fibrin. 3d. That the softening of coagulated fibrin is an elementary pathological condition of frequent occurrence, distinct from suppuration, and constituting a considerable proportion of the cases generally denominated suppurative phlebitis." These remarks throw a flood of light upon numerous morbid conditions of the blood, separating them from inflammation, and accounting for obstruction in the blood vessels altogether independent of that pathological state. There especially resulted from them, in conjunction with the further original observations of Gulliver as to the fatty degeneration of blood vessels,* the now established fact of impaction of portions of the clot so broken up in distant vessels. That foreign solid bodies floating in the blood would obstruct the smaller vessels and occasion exudations was first shewn by the experiments of Magendie, Cruveilhier, Gaspard, and others, who injected starch, quicksilver, and various substances into the blood, with the effect of producing fatal inflammations. In like manner fragments of the blood clot, softened and broken up in the manner described by Gulliver, have been shewn, by Kirkes, Virchow, Tufnell, and others, to be carried by the circulation to the brain, lungs, or extremities, where they become impacted in smaller arteries, producing hæmorrhage, inflammation, and diminished nutrition in distant organs.

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* See Med.-Chir. Trans. for that year, vol. xxii. p. 136.

On all these topics it is to be observed that, whilst throughout Germany these facts have been widely published, under the new terms of Thrombosis and Embolismus, the name of Gulliver has never been mentioned. Well may that gentleman remark in his recent lectures on the blood, speaking of physiological science, " Certain it is that many branches of it—which have been well cultivated and wrought out in this country—are afterwards transferred to the continent, and published in books there, and then translated and brought back as novelties to us, in such simplicity—not to say duplicity—as to the real origin of the facts, that they are actually paraded as part and parcel of foreign genius and discovery."

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* See Med.-Chir. Trans. for 1843, vol. xxvi. p. 86.

General view of diseases of the blood.—To enter at length into all the diseases of the blood is here impossible. I shall therefore content myself, in conclusion, with giving a list of the chief alterations to which it is subject in man :—

1. Increase or diminution of the blood as a whole—*Plethora, spanæmia.*
2. Increase or diminution of the coloured corpuscles—*Polypyrenæmia* (πυϱην, nucleus), *oligo pyrenæmia.*
3. Increase of the colourless corpuscles—*Leucocythæmia.*
4. Increase of the fatty molecules—*Lipæmia.*
5. Increase of the fibrin—as in *inflammations.*
6. Decrease of the fibrin—as in *fevers, exanthemata, purpura hæmorrhagica,* and *scurvy.*
7. Increase of albumin—as in *scrofula, cancer,* and *morbid growths.*
8. Decrease of albumin—as in *Bright's disease, cardiac dropsy,* and *puerperal fever.*
9. Increase of uric acid—*Uræmia,* as in advanced *Bright's disease, rheumatism, gout,* and *calculi composed of lithates.*
10. Increase or diminution of earthly salts—as in *rachitis, malacosteon, calculi composed of phosphates.*
11. Increase of sugar—*Glycohæmia,* as in *diabetes, calculi composed of oxalates.*
12. Increase of bile—*Cholæmia,* as in *jaundice.*
13. Poisons of various kinds—*Toxihæmia,* divided into:
    - *a. Animal poisons,* such as from *putrid pus* or *ichorhæmia* (commonly called pyhæmia) ; from *syphilis, small pox, scarlatina, measles, erysipelas, glanders, plague,* &c. ; from *bites of venomous animals,* &c.
    - *b. Vegetable poisons,* such as from *opium, belladonna, aconite, Calabar bean, strychnia,* &c., &c.
    - *c. Mineral poisons,* as from *carbonic acid gas, sulphur vapour, mercury, arsenic,* &c., &c.

ANIMAL HEAT.

Many of the processes we have described are accompanied by an exchange of chemical elements, which, in the act of forming new combinations, evolve heat. Thus the union of oxygen with the blood in the lungs, the formation of carbonic acid gas in the capillaries, and the oxidation of hydrogen, sulphur, and phosphorus within the system, make up together the amount of animal heat found in the body. The average temperature, as estimated by placing a thermometer in those internal parts which are most easily accessible, is from 98° to 100° F. (36·6° to 37.7° C.). In children it is about 2° higher. In Febrile diseases it has been observed to rise to the height of 108°·5 F. (42·5° C.) in children, and to 107° F. (41·6° C.) in adults. In Asiatic cholera it may sink to 77° F. (25° C.), or even lower, and the breath itself feels cool to the naked hand. The natural temperature of the body, though slightly affected by temperature, food, and exercise, is on the whole pretty stationary ; a circumstance which for the most part is owing to the power of evaporation possessed by the skin. Hence the danger of suddenly checking perspiration, by exposing the surface to cold. The temperature of the various tribes of animals differs considerably, birds having a higher, and reptiles and fishes a much lower, temperature than mammals, according to the medium they live in. They cannot, however, endure severe changes in external heat and cold. Man alone, by his power over food and the supply of artificial clothing and exercise, is enabled to bear without injury extremes of atmospheric temperature that no other animal could endure.

All young, as well as very aged animals, have less power of sustaining heat, and are more influenced by the surrounding temperature. It has also been observed that animals born blind are more dependent on external temperature than those which can see at the moment of birth. This is dependent on the conjoint circumstances that the organs of the former are not so fully developed as those of the latter animals before birth, and that while the one cannot obtain food for itself, the other can do so.

We have seen that more oxygen is taken in by the lungs than escapes from them in the form of carbonic acid gas. This excess, by uniting in the tissues with the carbon and hydrogen received into the system as food, produces heat ; and the carbon in its conversion into carbonic acid, and the hydrogen in its change into water, gives off exactly the same amount of heat as if these processes had been carried on out of the body. Hence the quantity of heat generated bears a direct relation to the activity of respiration and the supply of food. Thus the respiratory process is most active in birds, and they possess the highest animal temperature; and in reptiles, in whom respiration is slow, the heat evolved is much less. Even in man all the circumstances which induce rapid breathing, such as exercise, occasion increased heat. As regards the influence of food, we observe that in northern climes, where the oxygen in the air is more abundant, because the air is more condensed, the quantity of food taken is greater than among the inhabitants of tropical countries. The nature of the food, also, in the one, abounding in fatty and oily substances rich in carbon and hydrogen, is better adapted to combine rapidly with the excess of oxygen than the vegetable and starchy compounds used in others. The effects of alcohol, a highly carbonaceous substance, in keeping up animal heat, is in like manner thus explained; a substance which, rapidly entering the blood, combines with the excess of oxygen, and thus supports the temperature of the body when exhaustion from want of food, or from exercise too long continued, has been occasioned. Starvation also, as shewn by Chossat, has a marked influence in diminishing the temperature. A starving man is soon frozen to death. Thus, in the words of Liebig, to whom we are indebted for establishing this chemical theory of animal heat, "The animal body acts as a furnace, which we supply with fuel. It signifies nothing what intermediate forms food may assume, or what changes it may undergo in the body; the last change is uniformly the conversion of its carbon into carbonic acid, and of its hydrogen into water; the unassimilated nitrogen of the food, along with the unburned or unoxidised carbon, is expelled in the urine or in the solid excrements. In order to keep up in the furnace a constant temperature, we must vary the supply of fuel according to the external temperature—that is, according to the supply of oxygen. Hence, in the animal organism two processes of oxidation are going on—one in the lungs, the other in the capillaries. By means of the former, in spite of the degree of cooling, and of the increased evaporation which takes place there, the constant temperature of the lungs is kept up, while the heat of the rest of the body is supplied by the latter."

It has been supposed that this chemical theory of animal heat requires modification, because—1st. Helmholz has shewn that heat to the extent nearly of $\frac{1}{3}$° F. is generated in the muscle of a frog recently cut from the animal, and caused to contract. 2d.

Because Dr Bennet Dowler of New Orleans has shewn that, after death from yellow fever, the temperature of the body often rises. In one case the highest temperature during life was 104° F.; ten minutes after death it had risen to 109° in the axilla; fifteen minutes afterwards it was 113° in an incision in the thigh, and was 109° there in one hour and forty minutes. In three hours after the removal of all the viscera, a new incision in the thigh gave 110°. And 3d. Because the observations of M. Martens have shewn that of two birds, under similar conditions as regards the chemical conditions producing heat, such as ducks and geese, the ducks always possess the higher temperature. But, however difficult it may be to account for these facts, there can be little doubt that animal heat is produced by similar molecular changes in the animal body as those which occasion heat in general, and these unquestionably are attributable to chemical transformations.

EXCRETION BY VARIOUS ORGANS.

We have already seen that the textures of the body, while they are continually assimilating new particles of matter from the blood, are constantly giving up to that fluid the particles which have lived and are worn out. These in a fluid form, but more or less chemically changed, constitute the fibrin, and a portion of the fat, extractive matters, and salts which circulate in that fluid. They are the results of the disintegration of the tissues—that is, of the secondary digestion of organic matter which takes place in the body; and being useless, are now separated from the economy in the following ways, as—

1. *Excretion from the lungs.*

A large amount of watery vapour and of carbonic acid are, as we have seen, continually passing off from the lungs. The water thus exhaled daily, varies from 6 to 27 oz.; and the carbon, in the form of carbonic acid, separated in the same space of time varies from 4 to 12 oz. troy. In addition, then, to considering the lungs as organs which supply oxygen to the blood, and as supporters of animal heat, they must be regarded as an apparatus of excretion, whereby oxygen, hydrogen, and carbon are continually separated from the body. Under the heads of "Respiration" and of "Animal Heat" we have sufficiently dwelt on these points.

2. *Excretion from the liver.*

Portal blood.—The blood which supplies the liver is, like that which goes to the lungs, venous, and the portal vein which carries it there originates for the most part from the capillaries of the intestines (Plate IX. fig. 1, 12). Hence it differs from other blood in frequently containing principles derived from the primary digestion, more especially fat, dextrine, and sugar; whilst it does not possess so much fibrin, a substance chiefly formed from the secondary digestion, so that its clot is deficient in firmness. The food, in traversing the alimentary canal, not only parts with substances which enter the systemic circulation to form blood, but also with portions of its material which enter the blood-vessels, and are at once directed through the portal vein to the liver, in order to form bile. We can easily understand, therefore, how rich eating and little exercise favour the production of those symptoms which are denominated *bilious.*

Structure of the liver.—When the blood arrives by the portal vein at the liver, it breaks up into a multitude of minute capillaries, which, with a mass of secreting cells filling up the interspaces between them, are arranged in small masses or lobules. The external portion of these lobules contain the portal capillaries coming from the interlobular veins, which, inosculating together, terminate in their centre in small vessels, the origins of the hepatic vein, which conveys the blood, after having thus traversed the liver, into the vena cava (Plate XIII. fig. 1). The hepatic cells fill up the spaces or net work between the capillaries, and these occur in groups, their walls compressed together so as to give them a pentagonal shape (Plate XII. fig. 15). Great discussion has taken place as to the mode of their arrangement within the organ, and the manner in which the gall ducts originate. According to Kiernan, they arise from the external portion of the lobule, as figured Plate XIII. fig. 4. Beale describes the liver as formed of tubes, often terminating in cæcal extremities, and lined with the cells which constitute the ultimate ramifications and ducts of the glands (Plate XIII. fig. 3). Chrzonszczewsky and others consider that a minute passage exists around each hepatic cell, and that the biliary ducts originate in these passages (Plate XIII. fig. 3). These small ducts they have succeeded in injecting. It cannot be said, however, that this difficult histological question has been definitely decided. The action of the cells is to attract and select from the blood, materials which they elaborate into bile in their interior, and this is subsequently discharged into ducts, and accumulated in a gall-bladder until it joins the food in the duodenum, as previously described.

The bile is a viscous, brown or greenish fluid, of strong bitter taste. The solid matter it contains varies from 9 to 17 per cent. The quantity of it formed daily has been estimated at 3½ lbs. (Bidder and Schmidt. See p. 204); but this varies under a great variety of circumstances. It is composed of water holding salts in solution, with mucus, colouring matter, and fat. The salts are those of soda, potash, and ammonia, in combination with two resinous acids—the *glychocholic* and *taurocholic* acids, the latter of which contains sulphur as a constituent. The colouring matters are five in number. (See p. 32.) The fatty matter is composed principally of cholestrin, mingled with a small proportion of fatty acids and various products of the disintegration of the tissue as *leucin*, *tyrosin*, *xanthin*, and *hypoxanthin*. Oxide of iron is a common constituent of the ashes of bile, and copper is found in healthy bile and biliary calculi.

Bile is excreted in two ways. A portion of it, including the colouring matter, passes through the whole alimentary canal. The greater portion, however, during its transit is absorbed into the blood, and is ultimately carried off by the respiratory process in the form of carbonic acid. The amount of the excretion in these two ways varies greatly, one being to a certain extent increased if the other be diminished. It is absolutely necessary for the bile to be conducted out of the system, and if, through any obstruction in the duct, it be prevented from being discharged into the duodenum, it accumulates in the blood, producing jaundice, and acts as a poison. Although, therefore, the bile is useful as a secretion in operating on the chyme, there can be no doubt that its principal function is that of purifying the blood of hydrogen and carbon, and acting as an excretion.

The orifice of the common bile duct in the duodenum is much narrower than the duct itself, and is easily closed by the contraction of the intestine. The *vis a tergo* exerted by the fluid secreted is not sufficient to open it, and the bile therefore passes into the gall-bladder. When, on the other hand, chyme passes from the stomach in quantity during digestion, it probably distends the duodenum, and thus tends to open the orifice of the duct, thereby facilitating the flow of bile. It has been thought that the gall bladder contracts by reflex action when the mucous coat of the bowel or the extremity of the duct is stimulated by food or drugs. But I have satisfied myself by several experiments, (1) that the gall bladder is not contractile on the application of the strongest stimuli; (2) that it has no proper muscular coat, but only a few fibre cells; and (3) that irritation of the orifice of the duct in rabbits and dogs causes no flow of bile. On the other hand, strong contraction of the diaphragm and muscular parts surrounding the gall bladder compresses it, and immediately causes a flow of bile.*

Free fat.—The liver also secretes a large quantity of free fat, which, accumulating in the cells of the organ, often causes so-called *fatty liver*, as was first shewn by Bowman. It collects at first in the interior of the hepatic cells in the form of minute molecules, which, uniting together, form granules, and these at length melt into large globules, which completely distend the cell, and cause disappearance of the nucleus (Plate XII. figs. 13 and 14). This form of structural atrophy or fatty infiltration causes great enlargement of the organ, the accumulated fat taking the place of cell texture. All stall-fed animals present this condition of the liver to a moderate extent. The manner in which this lesion is induced artificially in the livers of geese at Strasburg, in order to make the celebrated *Paté du Foie Gras*, is highly illustrative of the function of the organ, and of the manner in which it becomes diseased in hot climates. The animals are confined in a heated atmosphere, and largely supplied with food. Want of exercise and heat diminish the respiratory function, and the excretion of hydro-carbon from excess of food is therefore forced upon the liver. Under these circumstances, it cannot be wholly got rid of, and is stored up in that organ in the form of fat.

Glycogen.—It has been shewn by Bernard that the liver constantly secretes a substance which, when separated, presents all the physical and chemical properties of hydrated starch. He supposed that the moment this substance comes in contact with the blood of the hepatic vein, it is converted into sugar, which in its turn is decomposed by the oxygen of the air in the lungs, and there disappears. If the pulmonary action be insufficient to accomplish this, the sugar becomes in excess in the blood generally, and is excreted by the kidneys, forming, as it was supposed, the disease known as *diabetes*. Hence also why a section of the pneumo-gastric nerves, injuring the fourth ventricle of the brain, where these nerves originate, and occasionally blows on the head, may occasion diabetes.

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* See the Author's paper in *British Medical Journal*, Jan. 7. 1871.

The experiments on which this theory was founded were numerous, were carefully repeated, and appeared at first to be very convincing. In a dog that had been fed exclusively on animal food for six weeks the portal vein was tied, and the animal killed. No sugar was then shewn to exist in the portal blood going *to* the liver, while it *did* exist in the liver itself, and in the hepatic blood coming *from* the liver. Again, in a rabbit it was shewn that no sugar was present in its urine. The fourth ventricle was then perforated from above with a strong needle or a stylet, and in an hour diabetes was produced. Subsequent experiments, however, by Pavy, confirmed by those of M'Donnell and others, have shewn that *during life*, or *immediately* after death, there is no sugar in the liver or in the blood of the right side of the heart, although glycogen or the amyloid substance is present. Hence its occurrence after death, as witnessed by Bernard, is entirely a *post mortem* phenomenon. No fact more strikingly exhibits the difference between living functions and dead properties, and how careful one should be not too readily to infer the existence of the former from an examination of the latter.

The liver, therefore, is associated with the lungs in excreting hydro-carbonaceous products. This is well shewn by the circumstance, that in those cases where the lungs imperfectly separate carbonic acid gas, the action of the liver is particularly apt to be disturbed. Thus, if more non-nitrogenised food be taken than can be got rid of by the lungs in the form of carbonic acid, the liver pours a greater quantity of bile into the duodenum, causing those symptoms known as *bilious*. This is what happens frequently to Europeans in tropical climates. The rarity of the atmosphere, and the little exercise which is taken, throws increased work upon the liver. The appetite is then too frequently stimulated by drugs and spices, which increase the disturbance, rendering a return to Europe necessary. All such persons, therefore, should carefully adapt a certain diet to the amount of exercise they take and the vigour of the respiration, avoiding carbonaceous, especially oily food, and alcoholic drinks, and living according to the simple habits of the natives.

Experiments of the Edinburgh Committee.—Considering the uncertainty that existed as to the secretion of bile, especially among medical practitioners, and the contradictory opinions held as to the influence of mercury and other drugs as cholagogues, I suggested to the British Medical Association at its meeting in Chester, 1866, to appoint a Committee to investigate the subject. This was agreed to, and the Committee, of which I was appointed Convener, applied itself for two years to one of the most laborious and difficult inquiries in the whole range of physiological and therapeutical investigations. The results arrived at may be shortly stated as follows :—*

1. That no kind of examination of the fæces can yield trustworthy results, because it is only a small portion of the bile derived from the liver and poured into the duodenum that is mixed with the alvine discharges, in consequence of the large quantity of it which is absorbed and decomposed during its passage through the alimentary canal. Purgatives, it is true, may cause a discharge of unchanged bile from the bowel in increased quantity, but this is no proof that the secretion of it is augmented. It only forces the bile in the upper part of the canal downwards and outwards, thus preventing its absorption and the changes in it which would otherwise take place. The only accurate method, therefore, of determining the amount of bile secreted by the liver, is by producing biliary fistulæ in living animals, and collecting the bile directly through such fistulæ with the gall bladder.

2. That the best animal for making such investigations with was the dog, because it was shewn by six series of experiments, conducted by Dr Wm. Rutherford, on these animals, with and without biliary fistulæ, that mercury produced in them exactly the same phenomena during life as it does on man, and that

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* See Report on the Action of Mercury, Podophylline and Taraxacum, on the Biliary Secretion, by the Edinburgh Committee of the British Medical Association—in the Transactions of British Association for the advancement of Science for 1868, and separately published. Edinburgh : Edmonston & Douglas, 1869. It is to the pages and tables in this Report that the subsequent references are made. See also the *British Medical Journal* for July 25th, 1868, May 8th, 1869, and July 24th, 1869 ; and "Medicine in Modern Times." London. Macmillan & Co., 1869, p. 193.

after death from poisonous doses precisely the same appearances were observed in the dead body.*

3. The Committee succeeded in establishing permanent fistulæ in nine dogs, with which they were enabled to pursue their investigations until the inquiry appeared to them to be exhausted.

4. In every case, the fistula being established, the whole of the bile secreted for 24 hours was collected in an apparatus, which is described in their Report,† for several consecutive days, so as to establish an average; and afterwards mercury was given in all its forms, in every possible way, and in all kinds of doses, and further collections of bile were made in the same careful manner to contrast with them. The results were carefully recorded day by day, the amount of bile accurately measured, its fluid, solid and saline constituents, determined by analyses, and the quantity of each of these calculated in relation to 100 grammes of the dog's weight, and to 100 grammes of the food consumed.

5. It was conclusively proved that on no occasion whatever did mercury increase the biliary secretion. The drug does not even influence it so long as neither purgation nor impairment of health are produced, but it is diminished as soon as either or both are induced. ‡

6. Podophylline, another drug which has been supposed to have a cholagogue action on the liver, was tried in the same careful way as mercury had been, and so far from increasing was found to diminish the solid constituents of the bile, and the fluid also when it occasioned purgation. §

7. Taraxacum extract, in doses of from 60 to 240 grains, was shewn to be quite inert.‖

8. Purgation, however produced, was shewn by the Committee invariably to diminish the quantity of the biliary secretion, a conclusion of great importance in a therapeutical point of view. This result is evidently due to the drain from the intestinal walls, which furnish portal blood, and from which in turn the bile is almost entirely formed.¶

9. The relation between the amount of bile secreted and the quantity of food consumed is not so close as has been supposed. Often the dogs while eating the same diet, and without any apparent disturbing cause, such as diarrhœa, secreted one half,

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* See Report, Table I., pp. 201, 2.

† Ibid. p. 200.

‡ Ibid. p. 222.

§ Ibid. p. 229, Tables XVII., XVIII., XIX.

‖ Ibid. p. 229, Table XX.

¶ Ibid. p. 229, Table XVI.

and on one occasion four-fifths less than on previous and subsequent days. Again, it was often observed that while the food was varied in quantity, the amount of bile secreted remained the same. On the other hand, withholding food altogether, causing partial starvation, was shewn greatly to diminish the secretion of bile.*

10. The size and weight of the animal were proved by the Committee to have no influence on the amount of bile secreted. Thus a large dog, weighing 19 kilogrammes (Dog 4), secreted on an average only 67.1 kilo's of bile daily, while a smaller dog (Dog 6), not one-third the other's weight, that is, 5.1 kilo's, secreted in the same time 113.8 kilo's of bile daily. Again, Dog 4, secreted 3.53 grammes of fluid bile per kilogramme of its weight ; Dog 7, 4.6 per kilo ; Dog 5, 21.8 per kilo ; and Dog 6, 21.8 per kilo. This result vitiates all previous calculations as to the amount of secretion in man, based on the calculations of the relative weights between him and the lower animals.†

11. Exercise was always observed to increase for a time the flow of bile from the fistulous openings in the dogs, a result probably due to the pressure upon the liver of the contracting abdominal muscles, whereby its contents were expelled. We have previously seen (p. 251) that forcible contraction of the muscles pressing upon the liver, may be seen to cause a copious flow of bile from the duct into the duodenum.‡

These conclusions of the Committee are based on a series of observations, embodied in 21 valuable tables, setting forth in a form that can be easily studied, the facts obtained during two years, from the nine dogs in which biliary fistulæ had been made. It is only justice to declare that science is indebted to the labour and perseverance of two members of the Committee, viz., Dr Wm. Rutherford and Dr A. Gamgee, for the physiological and chemical observations, and for the labour of drawing up the tables.

3. *Excretion from the Kidney.*

Structure of the Kidney.—A section through the kidneys shew that they consist of a medullary and a cortical substance. The former is composed of tubes which may be traced from the pelvis of the organ, diverging outwards ; dividing dichotomously, and becoming smaller and smaller. They diminish from 1.300th to 1.600th of an inch in diameter. In the larger portion of the tube, they are lined with polygonal nucleated cells compressed together (Plate XIII. fig. 10), but in their smaller portions, especially as they become convoluted in the cortical substance, they contain molecules and nuclei in various stages of development (Fig. 11). On carefully examining a section of the cortical substance of the kidney, it may be seen under a magnifying power of 20 diameters linear, to present the appearance figured Plate XIII. fig. 5, consisting of the convoluted *Tubuli uriniferi* and *Corpora Malpighiana.* The latter consist of a rounded mass of capillary blood vessels, which come off from the terminal branches of the renal artery, as figured Plate XIII. fig. 8. From them emerges an efferent vessel which divides and subdivides to form the capillary plexus of the cortical substance (Fig. 6), and also sends down branches to supply the tubes of the medullary substance. (Fig. 8, *cf.* and *b.*) Those Malpighian bodies are surrounded by a capsule, formed by the terminal expansion of the uriniferous tubule, as was first shewn by Mr Bowman (Fig. 9). This relation of the vascular and tubular structures of the organ, is well shewn in the diagram given by Frey (Plate XIII. fig. 6). A transverse section of the medullary near the corticle portion, under high powers (200 diam. lin.), shews the Malpighian body and its capsule, the tubes with their epithelial linings, the vessels surrounding them, and the fibrous stroma of the organ—after Eckar (See Fig, 7). The peculiar arrangement now described, whereby an abrupt retardation in the current of blood is caused by the sudden division of an artery in a number of minute branches, while the pressure remains constant, favours the ready passage of water from the blood through the capillary walls. The water is caught in the funnel-shaped expansions of the uriniferous tubes surrounding the Malpighian bodies, flows through the ducts, receiving and dissolving the secretion formed by the gland cells which line them, and passing along the uretors, is accumulated in the urinary bladder in the form of urine (Plate IX. figs. 1, 16, and 17). Its expulsion from thence takes place from time to time by an act of volition.

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* See Report, p. 229. † Ibid., p. 230, Table XXI. ‡ Ibid., p. 231.

The daily amount of urine discharged in a healthy person has been variously estimated. According to Prout it is 35 fluid ounces ; according to Parkes it is 52½ ounces. It is of a wine-yellow colour, and slightly acid in its re-action on vegetable colours. The average specific gravity varies from 1012 to 1030. Its composition, according to Becquerel, is as follows :—

Water				967.
Urea				14.230
Uric acid				.468
Colouring matter			inseparable	10.167
Mucus and animal extractive matter				
Salts	Sulphates	Soda		8.135
		Potash		
	Phosphates	Lime		
		Soda		
		Magnesia		
		Ammonia		
	Chlorides	Sodium		
		Potassium		
	Hippurate of soda			
	Fluate of soda			
Silica			traces	
				1000.000

The proportion of these constituents varies considerably, even in health, according to the amount and quality of the food and drink, the occupation, period of life, sex, and other circumstances. In disease, the variations are still greater. The quantity, as a whole, may be increased or diminished, and the saline constituents may be so augmented as to be deposited on cooling, causing the formation of various salts. The urine may also be loaded with foreign substances, as blood, albumin, pus, sugar, &c. Hence why a careful examination of this fluid is so important to the physician, as indicating a variety of morbid conditions, not only of the urinary organs themselves, but of the constitution generally.

The kidneys, therefore, separate—1st. A large quantity of the water which enters the body as drink ; 2d. Certain materials derived from the primary digestion ; and 3d. Matters the result of the secondary digestion, or disintegration of the tissues.

Excretion of Nitrogenous matters.—The principal object of the kidney is to separate two substances rich in nitrogen ; so that, while the liver may be considered as an organ excreting hydrocarbon, the kidneys must be regarded as organs which separate nitrogenous substances. The forms these assume are two, viz., urea and uric acid. (See pp. 13 and 14.) Of the former, 500 grains, or about an ounce, are excreted by a healthy man daily, and of the latter, somewhat more than 8 grains. Children between three and seven years of age excrete twice as much. According to Liebig, when the vital force in the albuminous tissues is no longer able to resist the chemical action of the oxygen which is conveyed to them in the arterial blood, it combines with their elements, and forms products, among which uric acid is the most important. But if sufficient oxygen and water be conveyed into the arterial blood, the greater part of the uric acid, or more insoluble salts, is converted into urea and carbonic acid ; so that the effete nitrogenised elements of the tissues reach the emunctories in a soluble form, a condition necessary for their ready secretion. Hence the more oxygen enters a tissue during its disintegration, the more complete will be the conversion of the insoluble uric acid into the soluble urea, and the more easy its elimination from the body.

In this manner is explained how the urine of the boa-constrictor is semi-solid, consisting almost entirely of bi-urate of ammonia, as the animal eats an enormous meal of nitrogenous food ; but being a cold-blooded, slowly-respiring animal, it takes in too little oxygen to convert the uric acid into urea. On the other hand, the lion and the tiger, equally carnivorous with the serpent, are rapidly-respiring, warm-blooded animals ; and although, from their violent muscular exertions, rapid and great destruction must occur, scarcely a trace of uric acid is found in their urine, as it is all converted into urea at the moment of its formation, in consequence of the abundant supply of oxygen. The non-nitrogenised elements of our food, however, considerably interfere with the conversion of uric acid into urea, because they also combine with oxygen. Hence, according to Liebig, man, being an omnivorous animal, partakes of a sufficient amount of food, rich in carbon, to prevent the complete conversion of insoluble uric acid into soluble urea ; consequently, the former substance appears in the urine, its proportion to urea being as 1 to 32.

Numerous researches of recent investigators have added great information as to the circumstances which increase or diminish the amount of the urea and uric acid excreted. The principle of these are, Food, Exercise, Season, and Disease.

Food.—The influence of an animal, vegetable, and mixed diet, was shewn several years ago by Lehmann, from experiments on his own person. The results were :—

DIET.	Quantity excreted in 24 hours in grammes.*				
	Solid constituents.	Urea.	Uric acid.	Extractive matters and salts.	Ratio of urea to solid constituents.
On a mixed diet	67.82	32.498	1.183	12.746	100:116
On an animal diet	87.44	53.198	1.478	7.312	100: 63
On a vegetable diet	59.24	22.481	1.021	19.168	100:156
On a non-nitrogenous diet	41.68	15.408	0.735	17.130	100:170

These conclusions have, in their main features, the quantities varying somewhat in different analyses, been confirmed by all experimenters.

Exercise.—The views of Liebig led to the supposition that muscular exertion, by causing waste of nitrogenous tissue, would largely increase the excretion of nitrogenous products by the kidneys. The investigations of Ed. Smith, Voit, and Lehmann, however, shewed that this increase was very trifling. A careful experiment by Messrs Fick and Wislicenus in 1866, shewed that it was diminished during their ascent of the Faulhorn, one of the Swiss Alpine peaks, about 2000 feet high. They took no albuminous food for seventeen hours previously, nor during the ascent, which occupied eight hours, nor for six hours after, their diet consisting of biscuits, starch, fat, and sugar. The examination of the urine gave the following results.†

	The average quantity of nitrogen excreted per hour was, by	
	FICK.	WISLICENUS.
	Grammes.	Grammes.
1. Urine of the night previous to the ascent—a period of 12 hours,	0.63	0.61
2. Urine of the period of ascent—8 hours and 10 minutes,	0.41	0.39
3. Urine excreted for 6 hours after the ascent,	0.40	0.40
4. Urine of the night following the ascent, after a good meal had been taken—10½ hours,	0.45	0.51

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* A gramme equals 15·434 grains.

† Lond. *Phil. Mag.*, 1866, p. 485.

The same conclusions were arrived at by Haughton, and by Parkes.* The latter subjected two soldiers to a careful and prolonged series of experiments, so that there can now be no doubt that muscular exertion does not increase the excretion of urea.

Season.—Dr E. Smith† found in himself that the daily quantity of urea varied from 219 to 700 grains, the average being 519 grains. It was increased with diminished temperature and with increased atmospheric pressure. It was greatest after the breakfast and tea meals, and least during the hours of the night and early morning.

Disease.—During the progress of most acute diseases, it may be observed that the urine becomes loaded with urates, a phenomenon indicative of excretion of the exuded matters. Hence in Pneumonia, Pleurisy, large abscesses, &c., it constitutes frequently an important element of the crisis. It is common in gout and rheumatism, two diseases in which the uric acid diathesis prevails, the first caused by derangement of the primary, and the last of the secondary digestion. A large increase in urates may also occur in cases, causing rapid emaciation of the body, as in fever and phthisis, in active dyspepsia, suppression of the perspiration, from blows and strains of the loins, affecting the kidneys, and diseases of the genital apparatus. Occasionally uric acid may be deposited in an insoluble form in the kidney or bladder, and aggregating, form a mass giving rise to a calculus. It constitutes a large proportion of these formations, even when they are composed of other ingredients, the nuclei on which they are deposited being, in the great majority of cases, formed of uric acid. When the kidneys are so diseased that their excretory functions are much interfered with, two phenomena are apt to occur, viz., dropsy and accumulation of urea in the blood. In the first case, the water, not escaping by its natural channel, transudes through the blood vessels, causing anasarca, which often commences in such affections, primarily, in the face. In the second case, nervous symptoms are apt to occur from poisoning of the blood, or, as it is generally called, *uræmia*, especially convulsions and coma. The pathological causes of this have been much discussed, but we cannot enter into this subject here.‡

In relation to the transformations producing urea and uric acid,—the various views advanced as to the place and mode and origin of these nitrogenous products,—we have seen they do not result from disintegration of the muscular tissue, as was once supposed, and whether they are caused by changes in the liver (Meissner*), in the kidney, blood, or elsewhere, requires further investigation.

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* Proceed. Roy. Soc., Nos. 89 and 94, 1867.

† Ibid. May 30. 1861.

‡ See the author's "Clinical Medicine," 5th edition, p. 1007.

Excretion of inorganic matters.—In addition to urea and uric acid, which are the excretory products of the nitrogenous compounds, the kidneys are constantly separating from the blood a large quantity of earthy salts. These are excreted to the amount of 250 to 300 grains daily. Lehmann found that the amount varied in men between 135 to 367 grains, and in women between 154 to 294 grains. The inorganic matter of the urine consists of salts formed by the combination of chlorine, sulphuric and phosphoric acids, with soda, potash, lime, and magnesia.

a. Chlorides of sodium and potassium.—Nearly all the chlorine found in the urine is combined with sodium. According to Hegar, the average quantity passed in 24 hours is 262½ grains. The quantity is diminished in all diseases in which an exudation takes place, such as pneumonia, pleurisy, &c. The amount of chloride of potassium in the urine is very small, varying from 15 to 30 grains.

b. Sulphates.—Sulphuric acid is found in combination with soda and potash. Lehmann found, that with an ordinary mixed diet, 105·3 grains of sulphates were excreted in 24 hours ; after a strictly animal diet for 12 days the amount rose to 155·9 grains, and after the use of a vegetable diet for the same time they fell to 87·69 grains.† The administration of pure sulphur increases the sulphur constituents.

c. Phosphates.—The phosphatic salts found in the urine are by far the most important. It has been found that from 56 to 77 grains of phosphoric acid are thrown off by the kidneys in 24 hours, which are united to the bases—soda, ammonia, lime, and magnesia. In healthy urine there are two kinds of phosphates—alkaline and earthy phosphates. The alkaline consist of acid phosphate of soda ; the earthy, of phosphate of lime and phosphate of magnesia. In decomposing urine there are also found the ammoniaco-magnesian or triple phosphate. The acid phosphate of soda is, according to Liebig, the principal cause of the acid reaction of urine. During digestion the urine becomes alkaline, from the excretion of the alkaline phosphate of soda derived from the food. Phosphoric acid forms, with lime and magnesia, compounds termed *earthy phosphates*, which are soluble only in a slightly acid fluid. Consequently those salts do not appear as precipitates in healthy urine ; but when from any cause the urea decomposes into carbonate of ammonia, and the urine is thus rendered alkaline, they are at once thrown down—the phosphate of lime being unchanged ; but the ammonia unites with the phosphate of magnesia, and forms a precipitate of ammoniaco-phosphate of magnesia, or triple phosphate.* The quantity of earthy phosphates varies considerably, but the average amount excreted in 24 hours may be stated at 15 grains. When healthy urine is distilled, the ammonio-phosphate of soda is formed by the action of the acid phosphate of soda on the urea ; but this salt does not affect the acid reaction of the urine.†

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* "Centralblatt," 1868, pp. 226 and 275.

† Lehmann, "Physiological Chemistry." Translated by Dr Day. Cavendish Society. Vol. i. p. 446.

The soluble phosphates must be regarded as derived directly from the food, or from the blood when in the act of forming the tissues. The insoluble or earthy phosphates, which constitute a part of the structure of the body, are conveyed to the urine during the disintegration of the tissues, more especially of the brain and nervous system. The greater part, however, is divided from without, as it occurs in considerable quantity in most elements of food divided from the vegetable kingdom, as in wheaten flour, and leguminous seeds, or beans and peas. The phosphates, like the urates, then, are of double origin, partly divided from the primary and partly from the secondary digestion.

The influence of disease on the increase of the earthy phosphates in urine is of great importance, indicating, as it does, serious functional, and frequently organic, mischief. Of the former, the depression, both mental and corporeal, in old people, and of the latter, the effects of local injury to the spine are examples. On the other hand, when the triple salt occurs in small quantities, and is free from phosphate of lime, the amount of functional or organic lesion is at a minimum, as in cases of dyspepsia. In the decrepitude of old age, abundant deposits of triple phosphate are common. In health, the urine is prevented from becoming ammoniacal from a protective influence exerted on it by the mucus which lines the urinary passages. But this is dependent on the integrity of the spinal nerves, and of the ganglionic system connected with them. When these nerves or the spinal cord are injured, so as to cause paralysis, large quantities of the triple phosphate and of the earthy salts are formed, often producing chronic thickening of the coats of the bladder.

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* Neubauer and Vogel, "Guide to Qualitative and Quantitative Analysis of the Urine." Translated by Dr Markham. New Sydenham Society. Fourth edition, p. 56.

† Ibid.

The chemical and histological examination of urine is now of the highest importance, not only physiologically, but as enabling us to arrive at a diagnosis of the diseases of the urinary organs, and to determine the nature of the treatment. This will be subsequently referred to at length. (See Practical Physiology.)

4. *Excretion from the Skin.*

The skin not only serves as a very efficient protective covering to the body, but is a most important organ, constantly excreting watery and fatty matters. The epidermis, hair, and various appendages which grow from the surface, may, in addition to the special purposes they are fitted for, also be regarded as excretions. The structure of its various parts may be noticed separately.

The epidermis, or scarf skin, forms the outer layer of the skin, and consists of epidermic cells, round below, compressed above, and flattened externally (Plate XIV. fig. 4 *a*). It varies in thickness in different parts of the body, being thin over the lips and flexures of the joints, and thick where it is subject to pressure, as on the fingers and heels. On making a thin vertical section from without inwards, it is seen in the last situations to be composed of flattened nucleated scales adhering together. Below they are fusiform (Fig. 4, *b*), and between the papillæ or projections of the chorium, serving as follicles, they may be seen in all stages of formation,—molecules, nuclei, and cells, &c. As they are pushed outwards, they undergo a chemical change, the walls being at first soluble, but afterwards insoluble in acetic acid, and undergoing what is called the horny transformation.

The cutis or dermis, also called *corium* or leather skin, constitutes the deeper layer of the skin, is composed of areolar and elastic fibrous tissues, which vary in different proportions in various parts of the surface. When great elasticity is required, as in the axilla, the elastic tissue predominates ; where resistance is demanded, as in the sole of the foot, there is a close mesh-work of areolar tissue. It also varies in thickness in different parts of the surface, being thin and delicate over the prepuce and eyelids, and thick when pressure is necessary, as on the sole of the foot. It may thus vary from 0.24 to 2.80 m.m. (Henle). The cutis rests on a layer of subcutaneous fat which gives symmetry and roundness to the figure; externally it exhibits a series of ridges or projections called *papillæ*, which are embedded in depressions of the cuticle. These vary in shape and size. They are large, more numerous and conical on the tongue, palms of the hands, and soles of the feet, their average length being 1.100th of an inch, and breadth at the base 1.250th of an inch. They are richly furnished with capillaries in the form of loops derived from an arterial twig from the arterial plexus. The vascularity is greatest where the ridges are most marked, and the sense of touch best developed. Hence the loops of nerves and blood vessels are more numerous in the papillæ of the fingers than on the back of the hand. Some papillæ are only furnished with blood vessels, others with nerves, and a third kind with both. They have been considered, therefore, as vascular and tactile, the former being most numerous. (See Sense of Touch.)

The sudoriferous or sweat glands lie at various depths in the true skin. They consist of a tube, blind and convoluted into a ball at its furthest extremity, which terminates externally on the surface of the cuticle. The tube is of the same diameter throughout, about 1.1700th of an inch, runs a straight course in the corium, but on passing through the epidermis, becomes spiral. In the first position, it is formed of a firm membrane, lined by epithelium ; in the second, it has no distinct coat, the spiral portion being a mere groove or channel in the epidermis, the cells of which are twisted in various directions to form its walls, as was pointed out by Rainey. These glands are scattered abundantly throughout the whole skin, but are most numerous in the palms of the hands and soles of the feet. In these situations, according to Krause, there are 2736 in each superficial square inch. In the same space on the back of the hand there are 1500; on the forehead and neck, 1300; on the breasts, belly, and arms, 1100; on the cheeks and thighs, from 500 to 600; and on the back, 400. Wilson estimates the number on the palm of of the hand at 3520 per square inch.

These glands secrete the sweat, a watery fluid which is for the most part carried off from the surface in the form of vapour as fast as it is separated. When, from increased exertion or other cause, the perspiration is augmented in quantity, or when, from a greater degree of moisture in the atmosphere, it is not readily evaporated, it becomes visible in the form of minute drops, which distil from the surface. The fluid consists principally of water, holding in suspension a few epithelial scales and fatty particles, and in solution a small quantity of the salts of soda, potash, and lime, with a trace of oxide of iron. Its reaction is acid to test paper, though it becomes alkaline after long exposure to the air. In diseased conditions, uric acid, grape sugar, albumin, and biliary colouring matters have been found in it, and occasionally therapeutical substances taken into the economy, such as benzoic, succinic, and tartaric acids, iodine and iodide of potassium. Funke pointed out that, during excessive sweatings, a larger amount of urea was excreted in the sweat than was generally supposed,—in one experiment so much as 6½ grains in one hour,—so that nitrogen may be eliminated from the body by this channel to a considerable extent. The amount of sweat given off daily varies greatly—the maximum, according to Seguin, being 5 lb., and the minimum, 1 lb. 11 oz. 4 dr. The average quantity, according to Valentin, is 2½ lb. The maximum, according to Funke, is much higher; but little is positively known on this subject, as various parts of the surface secrete different quantities, and calculations made from one part and applied to the entire skin, can only be fallacious. There is an intimate relation between the functions of the skin and those of the lungs and kidneys,—the one being more active when the other is depressed. Animals, on being covered with an impermeable varnish die, with all the symptoms of asphyxia,—the lungs and right side of heart become congested, while the temperature of the body rapidly sinks 36 degrees. Again, skin diseases, and especially febrile eruptions, materially affect the kidney, and thereby give rise to secondary dropsies. The exhalation from the skin, also, is influenced through the nervous system, being increased by fear and terror, and diminished by anger and excitement. It is increased by depressing causes, exhaustion, and diseases, as well as drugs, which weaken the action of the heart.

The most important investigation in recent times as to the secretion of sweat, is that undertaken by Dr Weyrich of Dorpat.* His object was to determine the average and relative amount of the cutaneous transpiration from various regions of the skin, 1st, in healthy adults, under ordinary conditions; and 2d, the variations in this average produced by external and internal causes. He employed an instrument similar to Daniell's condensing hygrometer. The experiments continued over a year and a half, and were made upon himself. The results were as follows: *Season of the year.*—It is generally supposed that less fluid is eliminated by the skin in cold than in warm weather, but in those who follow indoor occupations, Weyrich found that season exercised little influence. *Variations in the pressure of the air* produced little influence. Perspiration, however, is favoured by a bright serene sky, and diminished in sullen, overcast days. *Temperature,* if increased or diminished, causes a corresponding increase or diminution in the amount of the perspiration. *Period of the day.*—It is more active in the morning and at noon. During the night it is 20 per cent. less than in the day. *Food* increases the perspiration, which is always augmented after every meal. Tea, coffee, and alcoholic liquids, greatly increase it, even to double the fasting average. *Exercise* of body always increases the perspiration, sometimes more than double the mean amount. Mental exhaustion or depression causes a diminution. *A mustard poultice* causes a local rise of 67 per cent. *Snow or ice* causes a fall of 51 per cent., but on reaction induces a rise of 16 per cent. *Friction with warm oil* causes a rise of 27 per cent. *Friction with a soft brush for five minutes* causes an increase of 80 per cent.

The Sebaceous glands are found in most parts of the skin, but are absent from the palms of the hands and soles of the feet. They are most abundant on the scalp and face (especially about the nose), the anus and scrotum. The *glandulæ odoriferæ* of the genital organs, and the *ceruminous glands* of the ears, are varieties of them. The orifices open sometimes directly on the surface (Plate XIV. fig. 5), but more commonly into the follicles of the hair (Figs. 1 and 2). They vary in size, in some places consisting of a simple tubular follicle, in others, of a small sac, which occasionally is lobulated (Plate XIV. fig. 5).

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* Die Unmerkliche Wasserverdunstung ver Menschligen Haut. Leipsig. 1862.

These glands secrete an oily fluid, which is sometimes semi-solid, and approaches the character of wax. Poured upon the surface of the skin, or lubricating the hair, it prevents these textures from being dried and cracked by the action of the sun and air. Hence it is more abundant in the races which inhabit warm climates. In these, and many of the lower animals, the sebaceous matter possesses a distinctive odour, whereby they can readily be traced by quick-scented dogs. Generally speaking, the oily matter excreted from the skin is conveyed directly to the surface of the hairs or other epidermic appendages in those parts of the integument which are supplied by them (Plate XIV. figs. 1 and 2).

The colour of the skin was formerly supposed to exist in a distinct membrane called the *rete mucosum*, situated between the epidermis and corium. It is now known to depend on the deposition of pigment in the lower cells of the epidermis, or those nearest the blood vessels, and to be influenced by the general laws which regulate the formation of pigment in the animal and vegetable worlds. (See Pigmentary Principles, p. 30.)

Hair.—A hair consists of a shaft and root; the former is that portion which projects beyond the surface, the root is that which is enclosed within a follicle fixed in the corium (Plate XIV. figs. 1, 2, and 3).

The shaft of the hair consists of epidermic cells compressed and aggregated together, and presents different appearances in various kinds of hair. Sometimes it is wholly cellular (Plate XIV. fig. 24), at others wholly fibrous (Fig. 25), and occasionally fibro-cellular, in varied proportions. Human hair is generally solid and fibrous, sometimes having imbricated scales on its exterior (Fig. 7); at others, a central medulla, the cells in which are more or less loaded with pigment (Figs. 3, *m*, and 8). Great variation exists in the structure of the shafts in the hair of different mammalia, several of which are given Plate XIV. figs. 7 to 25. The principal facts to be noticed are the increased imbrication and roughness of the external scales in the hair of the Indian bat (Fig. 14), and in the wool of sheep (Fig 16); the atmospheric air contained in cells of the hair in an Indian monkey (Fig. 11), lemur (Fig. 13), kangaroo (Fig. 18), rabbit

(Figs. 20, 21), mouse (Figs. 22, 23), armadillo (Fig. 23), and musk deer (Fig. 24); the fibro-cellular structure of the polar bear (Fig. 15); the peculiar form of hair in the ornithorynchus, &c. A knowledge of these facts has proved of the highest importance in medical jurisprudence. When a hair is allowed to grow, it tapers towards a point, and then splits up into fibres like a painter's brush, which become brittle, and break off. The oily and sebaceous matter which nature furnishes to lubricate this structure keeps them soft, and prevents such disintegration—hence, also, the use of oil and unguents for the hair.

The root of the hair is a very complicated structure, consisting of an inversion of the epidermis, and various layers of cells (Plate XIV. fig. 14). At the base of the follicle is a papilla, into the interior of which a blood vessel enters, that divides into capillary loops, and from which nutritive matter is supplied to the growing texture. Immediately outside this, is a mass of molecules, which are transformed into cells, and these, being pushed forward, become fusiform, then split into fibres, or arrange themselves so as to constitute the substance of the follicle or of the shaft (Fig. 3, *g*, *h*, and *l*). Exterior to the root, and surrounding the bulb, is a dense plexus of capillary blood vessels; and occasionally there are oblique fibres of organic muscular fibres attached to the bulb, the *errectores pilorum.* The whole is firmly fixed in its situation by the fibrous interlacements of the dermoid fibrous tissue, assisted by the swollen bulbous enlargements of the root itself. When, owing to deficient vascularity or nutritive power, the growth is diminished or arrested, the bulbous enlargement shrinks, becomes pointed, and the root of the hair falls out, and is not restored, constituting baldness.

The colour of the hair depends upon the presence of pigment secreted within the cells of the follicle. Well-authenticated instances of hair turning white in a short period, from excessive grief or anxiety, are known. According to Vauquelin, this is owing to the secretion of an acid fluid, which percolates the hair, and chemically destroys the colouring matter.

The number of the hairs in a given space is very various in different parts of the body. Henle, quoting Withof, states that in a quarter of a square inch there were in a moderately hairy man, 293 on the crown of the head, 225 on the back of the head, 211 on the frontal region, 39 on the chin, 34 on the *os pubis,* 23 on the forearm, 19 on the back of the hand, and 13 upon the anterior part of the thigh.

Hygrometric property of hair.—Hair, when dry, readily attracts moisture from the atmosphere on the one hand, and from the body on the other, and is thus an active agent in the process of imbibition. When moist, they elongate considerably; a property which has rendered hair, as was first pointed out by Saussure, valuable in the construction of hygrometric instruments. When dry and warm, they are easily rendered electrical.

Chemical composition of hair.—After maceration in cold nitric acid, hair, like horn, is soluble in boiling water, and the solution, after evaporation, becomes a gelatinous mass on cooling. Horny matter is distinguishable from coagulated albumin or fibrin by its being readily soluble in caustic fixed alkalies, but not in caustic ammonia. The ashes of hair, according to Vauquelin, amount to one-half per cent. of its weight, and contain oxide of iron, a trace of oxide of manganese, of sulphate, phosphate and carbonate of lime and silica. Black hair contains most iron, and light hair least.

The nails, like hairs, grow from an inversion of the epidermis at their roots, constituting a follicle, richly supplied with blood vessels, which pour out a fluid which becomes first molecular, then cellular, and lastly, flat and condensed to form a horny plate (Plate XIV. fig. 6). They give support to the extremities of the fingers and toes, and thereby minister to the sense of touch.

In the various classes of animals, the epidermic appendages serve the purposes of warmth, of defence, or as aids to the sense of touch; and the modifications they undergo,—as seen in horn, whalebone, the quills of the porcupine, the feathers of birds, the scales of fishes, the wing-cases and spines of insects, &c.,—embrace a singular variety of form, constituted of the same structure.

Absorption by the skin.—It has been doubted whether the skin covered with its epidermis is capable of absorbing fluids. This point was decided in the affirmative by Dr Madden, in 1837. He found experimentally—every precaution being taken—that there was absorbed through the skin during half an hour the body rested in a bath, 53 grains of fluid. This has been supposed to result from mere imbibition of the water into the external epidermic cells, although the statement of shipwrecked sailors, that immersion of the body even in sea-water allays thirst, points to the possibility of water, under certain circumstances, thus passing into the blood. Solid substances can only be absorbed by mixing them with some greasy material and using friction, when mercury, potassio-tartrate of antimony, and other substances may be made to enter the economy, and produce their peculiar physiological effects, such as salivation, vomiting, &c. Friction causes the unguent to enter the sebaceous and sudoriparous ducts, from which they are more rapidly absorbed than through the epidermis. Inoculation of poisons can only be effected when this external membrane has been penetrated, and communication with the capillaries of the cutis established. The notion that nutrition can be increased by smearing the surface with oil is altogether erroneous, as, even could fat be introduced into the blood by this channel, it could not, without the process of chylification, assist the histogenesis of that fluid.

On the whole, the epidermis is a very sufficient protection to the body, and the most deadly poisons do not readily penetrate it. Further, while shielding the tactile organs, it admits of impressions being conveyed to them with nicety and truth. Looking also at the number of glands existing in the dermis, and its great vascularity, we readily see how extensive lesions of, and diseases in, this important organ, such as from scalds, burns, or exanthematous and pustular eruptions, are so fatal.

Excretion from the Intestines.

We have seen that the solid nutritive matter received as food daily ought to amount to 30 oz.; of these, 25 oz. are absorbed, and only 5 oz. rejected daily from the intestines. In prisoners fed upon a full diet with brown bread, the average excreted amounted, according to the experiments of Smith and Milner, to 8·55 oz. These consist of certain parts of the food which have escaped the digestive process, of a viscous mucus, and of various secretions which have been poured into the alimentary canal during its passage. There are also numerous crystals of triple phosphate, shewing that earthy matters are excreted in large quantities by this channel. In the large intestine, and especially in the cæcum, a further chemical change is effected. In the latter situation the peculiar fæcal odour is first produced, owing, it is supposed, to the secretion of an acid liquid there, causing another kind of digestion. Here also the fæces assume solidity, which increases more and more as they approach the rectum.

Histological structure of fæces.—The microscope enables us to detect in fæces the cell walls of vegetable substances, the pulpy contents of which have been extracted ; spiral and other ducts of plants ; the epidermis of seeds, fruit, and barks ; entire granules of starch and chlorophyle granules, which have escaped the action of the teeth and solvent properties of the stomach ; portions of tendon, ligament, elastic tissue, cartilage, even of muscular fasiculi, and various other elements of the food in a fragmentary condition, which, from different causes, have remained undigested. Various forms of fatty matter, including adipose tissue and crystals of cholesterine, are not uncommon. Among the matters derived from the alimentary canal itself, may be mentioned the brown colouring matter of the bile ; epithelium cells, young and old, and various saline matters, constituting either amorphous deposits or presenting well-formed crystals, especially those of the ammoniaco-magnesian phosphate. Further, there may exist all the different products of diseased action, such as blood, pus, lymph, cancer, &c., together with various kinds of vegetable and animal parasites. All these substances may be lacerated, more or less digested, acted on and altered by various agents, and disintegrated in various ways. Yet their detection by the practical physician is frequently not only of importance in determining the nature of many important morbid states, but has frequently led to a curative treatment after numerous remedies had previously failed.

Chemical composition of fæces.—According to Berzelius, human fæces of consistence to form an adherent mass are composed of—

Water			73·3
Matters soluble in water	Bile	0·9	5·7
	Albumin	0·9	
	Peculiar extractive	2·7	
	Salts	1·2	
Insoluble residue of the food			7·0
Insoluble matters added in the intestinal canal—mucus, biliary resin, fat, and a peculiar animal matter			14·0
			100·0

The ashes of human fæces, according to Enderlin, are composed of—

Chloride of sodium and alkaline sulphate	1·367
Tribasic phosphate of soda . .	2·633
Phosphate of lime and phosphate of magnesia	81·372
Phosphate of iron . . .	2·091
Sulphate of lime	4·564
Silica	7·973
	100·000

The potash generally predominates over the soda, especially when the diet contains much flesh. The reaction of fæces is usually acid, although sometimes neutral or alkaline. According to Marcet, healthy human excrement contains a peculiar substance, crystalising in acicular, silky, four-sided prisms, commonly grouped in stellæ, containing sulphur, and having a composition expressed by the formula C_{78}, H_{78}, S_1, O_2. This he calls *Excretine.* Dr Austin Flint has also obtained a substance, which results from the decomposition of cholesterine, which he has named *Stercorine.* The experiments of Smith and Milner shewed that 41·8 grains of nitrogen are daily eliminated from the body in fæcal discharges. According to Planer, also, the gases in the intestines of dogs contained no oxygen, but in the small intestine great quantities of carbonic acid and hydrogen, whatever was the food ; while in the large intestine, carbonic acid and sulphuretted hydrogen are present. In the human large intestine, Ruge found the gases to consist of nitrogen, which preponderated after the use of a flesh ; of hydrogen after a milk ; and of carburetted hydrogen after a vegetable diet.

The coloration of the fæces by bile.—The normal colour of fæces is that of a dark yellow brown. It undergoes great variations in this respect, according to the amount of bilirubin present. In cases where the bile is prevented from passing into the duodenum, fæcal matters become white or clay coloured. Medical practitioners have long been in the habit of considering the appearance of the alvine evacuations as giving evidence of the amount of bile secreted from the liver, and have imagined that remedies which cause evacuations of unchanged bile in the stools have done so by stimulating the liver to increased secretion. It has now been proved, however, that mercury, taraxacum, and podophyllin have no stimulating action on that organ, and never increase the amount of bile secreted. (See Experiments of the Edinburgh Committee, p. 254.) All purgatives, however, by propelling the bile poured into the upper part of the intestinal tube rapidly through its whole extent, prevent its absorption or decomposition into the system, and of course augment its quantity in the alvine discharges. According to Voit, about 170 grains of the biliary acids are secreted daily by the human liver ; while, according to Bischoff jun., only 45 grains are discharged in the fæces : so that 125 grains disappear during their passage through the intestinal tube. Hitherto medical men have taken no pains to appreciate the amount of bile pigments or bile acids which are excreted daily from the economy ; and such is the difficulty of the inquiry chemically, that it is very doubtful, in the present state of science, if it could be accomplished. The fact, therefore, demonstrated by the Edinburgh Committee, that certain powerful drugs supposed to act upon the liver have no such action ; and that mercurial and other purgatives, while they may increase the amount of unchanged bile in the stools, produce—with starvation, poisoning, and all depressing causes—diminution and not augmentation, of the hepatic secretion, is of the greatest importance.

The peculiar odour of fæces.—Considerable discussion has taken place whether the characteristic odour of fæces is owing to the decomposition of bile, or to a peculiar secretion. Valentin is of the former opinion. If so, does it result from some chemical combination of sulphur, or from decomposition of the entire undigested residue of the food ? On these points little is known. On the other hand, the most offensive discharges often occur where little food is taken, and even where there has been starvation, as in the *colliquative diarrhœa* of exhausting diseases. Liebig also produced artificial fæces by acting on the albuminous and gelatinous compounds,—first with hydrate of potash, and then with sulphuric acid, which distilled, yields a liquid having the distinct and peculiar odour of human fæces. True fæcal matter, therefore, according to him, is the product of the imperfect oxidation which a portion of the histogenetic constituents of the food undergo in the course of their retrograde metamorphosis. That it is not putrefaction or decomposition, seems also to be shewn by the circumstance that the odour is peculiar, and unlike that of putrefaction or fermentation in azotised or non-azotised bodies.

Defæcation.—The process by which the fæces are expelled is partly voluntary, partly excito-motory. The will is exercised upon the abdominal and sphincter muscles, whereby the former are contracted, and the latter relaxed. These movements are associated with others,—such as the closure of the glottis, the fixation of the diaphragm, and the contraction of the rectum, causing a bearing down action, which is exerted in expelling the matters contained in the lower portion of the bowel. The mechanism of these combined movements, however, can only be understood by reference to what has subsequently to be described under the head of Excito-motory Actions (which see).

Derangements in defæcation.—These are of various kinds, constituting *constipation* from various causes—*diarrhœa*, *tenesmus*, *dysentery*, *lienteria*, and an unnatural appearance of the fæces themselves. There may be a mechanical obstruction in the alimentary canal of various kinds. This may cause an inverted peristaltic action in the tube, and the fæces may be forced back into the stomach, and vomited. This is *ileus*, or the *iliac passion*. The obstruction may also arise from the impaction of calculi of various kinds. One of these, composed of aggregated portions of the *caryopsis* of the oat, is still common in horses, and used to prevail largely in Scotland, where oatmeal is consumed as food. The University of Edinburgh possesses the largest collection of these calculi extant, formed by the second Monro. Similar concretions are found in cattle, deer, goats, &c., formed of straw, or the hair licked from their skins.*

GENERAL RESULTS OF THE EXCRETORY PROCESS.

The amount of excretory matters separated in the ways previously described, may be estimated as follows:—Of carbonic acid there are given off about two pounds, or seven cubic feet, of which an ounce and a half may be separated by the skin. Of water there is about six pounds separated, one half by the urine and fæces, and the other half by the lungs and skin. The urine contains ten times as much as the fæces ; and the skin gives off twice as much as the lungs, or somewhat more. As it is calculated that only five pounds of water pass into the body mixed with the food, the extra pound is supposed to be formed in the system by the union of oxygen with the hydrogen of the tissues. Of urea, about 500 grains are separated in the urine daily of an adult man, together with from seven to ten grains of uric acid. It is by these substances, which contain about fifty per cent. of nitrogen, that the azote which enters the body is almost altogether separated from it. The earthy salts pass out in minute quantity dissolved in the sweat, and are given off more largely by the urine, which contains daily four drachms and a half of chloride of sodium, four drachms of sulphate of soda and potash, two drachms of acid phosphate of soda, and about 15 grains of phosphate of lime and magnesia. In the fæces other four or six drachms of mineral matter may be passed daily, the chief portion of which is derived from the residue of the food. Besides the substances named, a certain quantity of fatty, colouring, extractive, and other matters are excreted, the amount of which has not been yet estimated.

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* See the Author's Clinical Medicine, 5th edition, p. 280, *et seq.*

In this way, the albuminous, fatty, and mineral ingredients of the food, after having entered the body to form blood, and through it to build up tissue, are ultimately ejected from the economy, after having undergone a series of histogenetic and histolytic molecular changes, and been metamorphosed by chemical, mechanical, and vital agencies. The mode in which this is accomplished is now tolerably well known. Doubtless several points have yet to be determined, and numerous details require investigation. But the great function of nutrition, as I have now placed it before you, may be said to be established in science. In the same manner that the chemist, following Dumas, recognises in nature at large the exchanges which are constantly going on between the mineral, the vegetable, and the animal worlds—the earth and air building up vegetables, these building up animals, and these on their decomposition being again restored to earth and air,—so does the physiologist in each animated creature trace the food through its changes until it is converted into tissue, has enjoyed life for a time, and is then decomposed, returning, though in an altered form, to the external world from whence it came.

The molecular law of development, formerly described (see pp. 54, 98), is singularly well illustrated by the function of nutrition as now explained. Food consisting of well formed organic matter, animal and vegetable, is disintegrated by the primary digestion. The histolytic molecules so produced become histogenetic ones, and build up the blood corpuscles. These are in turn disintegrated and dissolved to form the *liquor sanguinis*, but once more other molecules are obtained from it to keep up the growth of the tissues, whether nutritive or secretory. The histogenetic molecules so produced are again rendered histolytic by the secondary digestion, and, circulating in the blood, undergo various combinations before being excreted from the economy. In this manner the great function of nutrition is shewn to be essentially molecular.

Further, we cannot avoid observing that the process of nutrition is a continuous round, which, in the natural world, may be said to commence with the reception and terminate with the preparation of aliment, vegetable or animal, and that this is observable not only in the "chemical balance of organic nature," so beautifully described by Dumas, but in the incessant chemical compositions and decompositions, as well as structural formations and disintegrations, which are peculiar to all vital entities. If so, it must be apparent that our knowledge of the animal economy, and of the diseases to which it is liable, can only be elucidated by investigating the nature of such chemical and structural changes, together with the necessary relations that each one bears to the others, and that it is on such kind of knowledge alone that medicine, as a scientific art, can ever repose in security.

ABNORMAL NUTRITION.

The various modes in which nutrition becomes impaired can only be understood by knowing the different steps of the nutritive process. For ages medical men have been in the habit of considering the blood to be the primary source of numerous maladies, but our previous description of the process of nutrition must shew that the changes in this fluid, and the diseases which accompany them, are for the most part not primary, but secondary ; that is to say, they are dependent on previously existing circumstances, to the removal of which the medical practitioner must look for the means of curing his patient. This will become apparent, not so much by analysing the individual disorders to which the various organs and tissues of the body are liable, as by determining the fundamental pathological processes which are common to all parts of the frame. An enumeration and definition of these is all we can venture upon in this place.

Classification of Diseases of Nutrition.

Congestion, or excess of blood in a part.—This is an over-distension of the blood vessels, but more especially of the capillaries, with blood. It may be caused by injury to the vaso-motor system of nerves (see Functions of the Sympathetic Nerves); by mechanical impediments which obstruct the return of venous blood, and by irritation of the textures. However produced, congestion may be temporary, and disappear without producing much disturbance, or, if long continued, it may give rise to one or more of the following conditions:—

Fever.—When congestion is caused or accompanied by general excitement of the nervous system, it produces fever, a morbid condition, characterised by hot skin, accelerated pulse, furred tongue, thirst, and headache,—phenomena usually preceded by a sensation of cold or rigor. If caused by some poison introduced through the blood, it is called *primary*, the principal forms being *intermittent*, *remittent*, and *continued*. If produced by injuries to texture, either directly from violence, or indirectly from reflex action, causing internal inflammations, it is denominated *secondary* or *symptomatic*.

Dropsy, or effusion of serum.—When congestion is *passive*, or caused by mechanical obstruction to the flow of blood through the veins, serum transudes through the walls of the capillary vessels, and collects in various places, causing dropsy. If generally diffused, especially through the subcutaneous tissue, it is called *anasarca;* if limited to the peritoneal cavity, *ascites;* if local, *œdema.*

Hæmorrhage or extravasation of blood.—This may arise from direct injury to a blood vessel, from a wound, or from disease of its coats. Under such circumstances, it may be *arterial* or *venous*, the former distinguished by the blood being of a bright florid, and the latter by its being of a claret, colour. The capillaries are frequently ruptured from over-distension with blood, which is *capillary* or *congestive* hæmorrhage, causing dropsical effusions or inflammatory exudations to assume a sanguinolent character.

Inflammation, or exudation of liquor sanguinis.—When congestion is *active*, or arises from irritation of the textures, it may, if excessive, terminate in the exudation through its coats of the *liquor sanguinis.* This is inflammation ; an expression still used very vaguely by some pathologists, but which, thus defined, separates the morbid state accurately from congestion or fever on the one hand, and from dropsy, or the processes of growth, on the other. The exudation thrown out undergoes a variety of changes, producing various morbid conditions, according as it lives or dies.

Simple or inflammatory exudation.—This consists of the normal *liquor sanguinis*, which infiltrates the neighbouring tissues or collects in serous cavities. It then coagulates, and may undergo the following vital transformations :—1st, Into cells and fibres, forming *adhesive lymph*, as on the surface of serous membranes ; 2d, Into pus cells, constituting *suppuration*, as in mucous surfaces or in areolar texture (Plate III. figs. 17, 18, and 19) ; 3d, Into granule cells, forming *inflammatory softening* (Fig. 22) ; and 4th, Into various elementary tissues, such as the fibrous, vascular, cartilaginous, bony, &c. In this manner the exudation may be (1.) absorbed, or undergo *resolution ;* (2.) evacuated externally by discharge ; or (3.) assimilated to the body. It is the agent which forms abscesses, causes the healing of wounds, and the union of divided tendons, bones, &c.

Tubercle or tubercular exudation.—When an exudation, instead of undergoing the vital changes just referred to, assumes a yellow or grayish aspect and cheesy consistence, it is called *tubercle.* It consists of solid irregularly-formed bodies, called *tubercle corpuscles*, more or less associated with molecules and granules (Plate III. figs. 24 and 25). If disseminated in small grains, it is called *miliary ;* if in considerable patches or masses, it is *infiltrated tubercle.* When chronic, it may be *encysted*, or present the form of *cretaceous* or *calcareous masses.*

Cancer, or cancerous exudation.—When an exudation, instead of undergoing the vital transformations previously described, passes into cells and fibres, the former increasing endogenously, it is called *cancer* (Plate III. fig. 23). If hard, and principally formed of fibres from associated morbid growth, it is called *scirrhus;* if soft, often yielding a milky juice on pressure, it is *encephaloma;* if having a fibrous basis, this is so arranged as to form areolæ or loculi, containing a gelatinous gum or glue-like matter; then it is called *colloid cancer.*

Mortification, or moist gangrene.—When the exudation is poured out rapidly in such quantity as to paralyse the nerves, obstruct the blood vessels, and prevent the return of circulation in them, it dies, and undergoes chemical putrefactive changes, and is said to be mortified, or to be affected with moist gangrene. It differs from *dry* gangrene, which is slow death of pre-existing texture from want of nourishment. Sometimes it is epidemic, from external or unknown causes, resembling the blight which affects vegetables.

Ulceration.—When an exudation does not pass into the vital transformations formerly described, but presses upon the surrounding parts, obstructing the flow of blood in them, death of such parts takes place. Under these circumstances, the whole slowly disintegrates; loss of texture is occasioned, with breach of continuity; and an *ulcer* is formed. Ulceration may also be produced by the direct pressure of a foreign body, continued weight of depending parts, &c.

Morbid growths of texture.—Increased growth of tissues may assume various forms: the organ or structure may be enlarged in whole or in part, still maintaining more or less of its original texture, shape, and function—constituting *hypertrophy.* Membranes may become preternaturally thickened, causing more or less *induration*, whereby the movements of parts may be affected; or the calibres of tubes and ducts may be diminished, producing *stricture.* The vital transformations of an exudation into pus, granule, or other cells, must be regarded as a form of morbid growth, as well as the results of the healing process, which give rise to new tissues exactly resembling those previously existing in other parts of the body,—as in cicatrices, callus, &c. Lastly, such growths may assume the form of *tumour*, and may present the form of—1st, *Fibroma*, or fibrous growths; 2d, *Lipoma*, or fatty growths; 3d, *Angionoma*, or vascular growths; 4th, *Cystoma*, or cystic growths; 5th, *Adenoma*, or glandular growths; 6th, *Epithelioma*, or epithelial growths; 7th, *Enhondroma*, or cartilaginous growths; 8th, *Osteoma*, or osseous growths; and 9th, *Carcinoma*, or cancerous growths.

Morbid degenerations of texture.—This also may assume various forms. The organ or structure may be diminished in whole or in part, constituting *atrophy*, still, however, retaining its normal shape and function ; or the structure of the parts themselves may have undergone alterations, whereby their functions are impaired or destroyed. Such degenerations are of four kinds :—1st, They may, in a variety of ways, become indurated and shrivelled up, or converted into a waxy or glue-like material, apparently from an excess of one or more of the albuminous or gelatinous compounds. This is *albuminous degeneration.* 2d, They become softer, from an accumulation of fatty granules, either within cells or among the minute elements of the texture. This is *fatty degeneration.* 3d, In the same manner, pigment of various kinds is deposited in or replaces the tissue, which may be red, yellow, brown, green, blue, purple, or black, owing to chemical changes ascribable to extravasated blood or bile, or to some peculiar secretion. This is *pigmentary degeneration. Lastly*, the tissues may become infiltrated with mineral matter of various kinds, but generally with salts of lime in solution, which subsequently becoming solidified, impede or destroy function. Such is *mineral degeneration.*

Concretions.—These are non-organised and non-vascular productions, formed by the mechanical deposition and aggregation of various kinds of matter, generally in the ducts or cavities of the hollow viscera. They may be composed of albuminous, fatty, pigmentary, or mineral substances, but are separable from degenerations from their never being formed out of an organic structure. *Urinary concretions,* or calculi, are composed of the salts which are too predominant in the urine, and which have been precipitated round a central body or nucleus, formed within or introduced from without. *Biliary concretions* are formed of inspissated bile or of cholesterine. The former are black or mingled with more or less colouring matter of the bile ; the latter are white. *Intestinal concretions* are usually composed of hair or vegetable fibres, which have been swallowed and accumulated also round a central nucleus. *Mineral concretions,* composed of carbonates and phosphates of lime, are common in the mucous passages of various organs, especially the salivary, pulmonary, pancreatic, hepatic, and renal. They also occur in the veins, when they are called *phlebolites.* Occasionally they resemble starch grains, and are called *amyloid ;* and not unfrequently concretions are found really composed of aggregated or isolated starch corpuscles, which may be called *amylaceous*.

Parasitic growths.—These are of two kinds, vegetable and animal. The vegetable parasitic growths may be divided into such as grow on the surface (*Epiphyta*), or those that have been formed in the interior of the body, chiefly on the mucous surfaces (*Entophyta*). The animal parasites may also be divided into such as infest the surface (*Epizoa*), and such as are found in the interior of the body (*Entozoa*). To the former belong the several species of *Pediculus*, or louse; the *Acarus Scabiei*, or itch-insect; the *Entozoon folliculorum*, which inhabits the follicles of the skin; and the *Pulex penetrans*, or guinea-worm. The Entozoa are numerous, and may be divided into—1st, *Cystica*, or saccular worms; 2d, *Cestoidea*, or chain-worms; 3d, *Trematoda*, or flat worms; and 4th, *Nematoda*, or thread-worms.

Such is an enumeration and definition of the organic diseases of textures and organs. What are called *functional disorders* of the same parts, are such as leave no traces of their existence after death, and are for the most part simple excess or diminution of normal actions. It is only when these last lead to congestions and exudations, terminating in fever or vital transformations, and chemical changes producing degenerations, that a true structural lesion can be said to exist. The causes of these organic alterations of texture are to be sought—1st, In increased or diminished stimulation acting directly on the tissues themselves; 2d, In increased or diminished excitability of the nervous system operating upon them indirectly; 3d, In an altered condition of the blood; and 4th, In chemical transformations of texture. These may act separately or combined, and one may occasion the other.*

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* The author's views and investigations on all these topics will be found in his work on Clinical Medicine, 5th edit. 1868, illustrated by numerous figures. To this, as well as to the article Phthisis in Reynold's "System of Medicine," he must refer for more extended information.

INNERVATION.

The function of innervation, like that of nutrition, consists in the performance of various actions, widely different from each other, although associated together. These actions lead to the manifestation of intelligence, sensation, and combined motion, and are dependent on the vitality of complex organs—viz. the brain, spinal cord, and nerves.

STRUCTURAL ARRANGEMENT OF THE NERVOUS SYSTEM.

To the eye, the nervous system appears to be composed of two structures—the gray or ganglionic, and the white or tubular. The gray matter, when examined under high powers, may be seen to be much more vascular than the white, composed essentially of molecular matter, in which are imbedded nuclei and nucleated cells, varying in size and shape, connected together by a greater or less number of nerve-tubes, also varying in calibre. The white matter is essentially tubular. (See p. 94.) There are also bundles of gelatinous or flat fibres, the nature of which is much disputed, very common in the olfactory nerve and sympathetic system of nerves. There can be no doubt that some nerve-tubes run into the ganglionic corpuscles, whilst others originate from them. It is also now rendered certain that the same ganglionic cell may receive and give off nerve-tubes, each having distinct properties,—the one of conveying the influence of impressions to, and the other of conveying influences from, the nervous centres. (See pp. 65, 94.)

By *cerebrum*, or brain proper, ought to be understood that part of the encephalon constituting the cerebral lobes, situated above and outside the *corpus callosum;* by the *spinal cord*, all the parts situated below this great commissure consisting of *corpora striata*, *optic thalami*, *corpora quadrigemina*, *cerebellum*, *pons Varolii*, *medulla oblongata*, and *medulla spinalis.* In this way we have a cranial and a vertebral portion of the spinal cord.

In the cerebrum, or brain proper, the gray or ganglionic structure is external to the white or tubular. It presents on the surface numerous anfractuosities, whereby a large quantity of matter is capable of being contained in a small space. This crumpled-up sheet of gray substance has been appropriately called the *hemispherical ganglion* (Solly). In the cranial portion of the spinal cord, the gray matter exists in masses, constituting a chain of ganglia at the base of the encephalon, more or less connected with each other, as well as with the white matter of the brain proper above, and the vertebral portion of the cord below. In this last part of the nervous system, the gray matter is internal to the white, and on a transverse section presents the form of the letter X, having two posterior and two anterior cornua,—an arrangement which allows the white substance to be distributed in the form of nerves to all parts of the frame.

The white tubular structure of the vertebral portion of the cord is divided by the anterior and posterior horns of gray matter, together with the anterior and posterior sulci, into three divisions or columns on each side. On tracing these upwards into the *medulla oblongata*, the anterior and middle ones may be seen to decussate only at that place with each other, whilst the posterior columns decussate through the whole extent of the cord. (See Plate XV. fig. 11, and Plate XVI. figs. 1 and 2.) On tracing the columns upwards into the cerebral lobes, we observe that the anterior or pyramidal tracts send off a bundle of tubes, which passes below the olivary body, and is lost in the cerebellum (*Arciform band* of Solly). The principal portion of the tract passes through the *corpus striatum*, and anterior portion of the *optic thalamus*, and is ultimately lost in the white substance of the cerebral hemispheres. The middle column or olivary tract, may be traced through the substance of the *optic thalamus* and *corpora quadrigemina*, to be in like manner lost in the cerebral hemispheres. The posterior column, or *restiform tract*, passes almost entirely to the cerebellum.

In addition to the diverging tubules in the cerebral hemispheres which may be traced from below upwards, connecting the hemispherical ganglion with the structures below, the brain proper also possesses bands of transverse tubules, constituting the commissures connecting the two hemispheres of the brain together, as well as longitudinal ones connecting the anterior with the posterior lobes. In the spinal cord it results, from the investigations of Lockhart Clarke, that there is a communication between the various bundles of tubes throughout its whole extent—1st, Between the anterior and posterior spinal roots; 2d, Between the two lateral columns of gray matter; 3d, Between these and the brain above; and 4th, Between these and the nerves below. (See Plate XVI. figs. 1 and 2.) It is now also determined that many of the tubes in the nerves may be traced directly into the gray substance of the cord, and terminate there—a fact orginally stated by Grainger, but confirmed by Budge and Kölliker.

These observations, indeed, demonstrate that the numerous actions hitherto called *reflex* are truly direct, and are carried on by a series of nervous tubules running in different directions. There can be no doubt that they pass and operate through the cord; and hence the term *diastaltic* proposed by Marshall Hall instead of reflex, is in every way more appropriate.

GENERAL FUNCTIONS OF THE NERVOUS SYSTEM.

The great difference in structure existing between [the gray and white matter of the nervous system would, *à priori*, lead to the supposition that they performed separate functions. The theory at present entertained on this point is, that while the gray matter eliminates or evolves nervous force or energy, the white matter conducts to and from this ganglionic structure the influences which are sent or originate there. Not that the white matter is wholly without power of originating influences, because irritating the trunks, and especially the extremities of nerves, not only causes the transmission, but excites the influence which is transmitted. But that the function of the white matter is essentially that of *conductivity.*

The brain proper furnishes the conditions necessary for the manifestation of the intellectual faculties properly so-called, of the emotions and passions, of volition, and is essential to sensation. That the evolution of the power especially connected with mind is dependent on the hemispherical ganglion, is rendered probable by the following facts:—1. In the animal kingdom generally, a correspondence is observed between the quantity of gray matter, depth of convolutions, and the sagacity of the animal. 2. At birth, the gray matter of the cerebrum is very defective; so much so, indeed, that the convolutions are, as it were, in the first stage of their formation, being only marked out by superficial fissures almost confined to the surface of the brain. As the cineritious substance increases, the intelligence becomes developed. 3. The results of experiments by

Flourens, Rolando, Hertwig, and others have shewn that, on slicing away the brain, the animal becomes more dull and stupid in proportion to the quantity of cortical substance removed. 4. Clinical observation points out, that in those cases in which the disease has been afterwards found to commence at the circumference of the brain, and proceed towards the centre, the mental faculties are affected *first;* whereas in those diseases which commence at the central parts of the organ, and proceed toward the circumference, they are affected *last.*

The white tubular matter of the brain proper serves, by means of the diverging fibres, to conduct the influences originating in the hemispherical ganglion to the nerves of the head and trunk, whilst they also conduct the influence of impressions made on the trunk, in an inverse manner, up to the cerebral convolutions. The other transverse and longitudinal fibres which connect together the two hemispheres, and various parts of the hemispherical ganglion, are probably subservient to that combination of the mental faculties which characterises thought.

The spinal cord, both in its cranial and vertebral portions, furnishes the conditions necessary for combined movements; and that the nervous power necessary for this purpose depends upon the gray matter, is rendered probable by the following facts:—1st, Its universal connection with all motor nerves. 2d, Its increased quantity in those portions of the spinal cord from whence issue large nervous trunks. 3d, Its collection in masses at the origin of such nerves in the lower animals as furnish peculiar organs requiring a large quantity of nervous power, as in the *Triglia volitans*, *Raia torpedo*, *Silurus*, &c. 4th, Clinical observation points out that, in cases where the central portion of the cord is affected previous to the external portion, an individual retains the sensibility of, and power of moving, the limbs, but wants the power to stand, walk, or keep himself erect, especially when the eyes are shut; whereas, when diseases commence in the meninges of the cord, or externally, pain, twitchings, spasms, numbness, or paralysis, are the first symptoms present, dependent on lesion of the white conducting matter.

The white matter of the cord acts as a conductor, in the same manner that it does in the brain proper; and there can be no doubt that the influence arising from impressions is carried not only along the fibres, formerly noticed, which connect the brain and two portions of the spinal cord together, but along those more recently discovered, which decussate or anastomose in the cord itself (Brown Séquard), and are connected with the ganglionic cells of the gray matter.

The nerves of the body consist, for the most part, of nerve-tubes running in parallel lines. Yet some contain ganglionic corpuscles, as the olfactory and the ultimate expansion of the optic and auditory nerves ; whilst the sympathetic nerve contains in various places not only ganglia, but gelatinous flat fibres. The posterior roots of the spinal nerves possess a ganglion, the function of which is quite unknown. These roots are connected with the posterior horn of gray matter in the cord, while the anterior roots are connected with the anterior horns. As regards function, the nerves may be considered as—1st, Nerves of special sensation, such as the olfactory, optic, auditory, part of the glosso-pharyngeal and lingual branch of the fifth. 2d, Nerves of common sensation, such as the greater portion of the fifth, and part of the glosso-pharyngeal. 3d, Nerves of motion, such as the third, fourth, lesser division of the fifth, sixth, facial, or *portio dura* of the seventh, and the hypo-glossal. 4th, Senso-motory or mixed nerves, such as the pneumo-gastric, third division of the fifth, and the spinal nerves. 5th, Sympathetic nerves, including the numerous ganglionic nerves of the head, thorax, and abdomen. These govern the excito-motory, excito-nutrient, excito-secretory, and vaso-motor acts of the internal viscera and organs of sense.

It is very probable that some nerves may have other properties than those now referred to, which may be peculiar to particular tubules. Thus Brown Séquard considers the influences arising from tickling, temperature, and pain to be in their character distinctive, and to be conveyed by peculiar nerve-tubes.

Sensibility.—All nerves are endowed with a peculiar vital property called *sensibility*, inherent in their structure, by virtue of which they may be excited on the application of appropriate stimuli, so as to transmit the influence of the impressions they receive to or from the brain, spinal cord, or certain ganglia, that may be considered as nervous centres. (See p. 179.) The nerves of special sensation convey *to* their nervous centres the influence of impressions caused by odoriferous bodies, by light, sound, and by sapid substances. The nerves of common sensation convey *to* their nervous centres the influence of impressions caused by mechanical or chemical substances. The nerves of motion carry *from* the nervous centres the influence of impressions, whether psychical or physical (Todd). The mixed nerves carry the influence of stimuli both to and from, combining in themselves sensory and motor filaments. Although the sympathetic nerves also undoubtedly carry the influences of impressions, the direction of these cannot be ascertained, from their numerous anastomoses, as well as from the ganglia scattered over them, all of which act as minute nervous centres. But there *are* cases where certain psychical stimuli (as the emotions) act on organs through these nerves, and where certain diseases (as colic, gallstones, &c.) excite through them sensations of pain.

Rapidity of the nerve current.—This problem has engaged the attention of physiologists for one hundred and fifty years, but has only recently been solved, through the labours of Helmholz, who, by applying the principle of Pouillet's chronoscope, ultimately constructed a *myographion*, by which we are enabled to measure the velocity of the nerve current. (See Plate XX. fig. 1.) Instead of being inconceivably swift, as Müller supposed, it now admits of demonstration to be in the frog from 26 to 30 yards in a second. (See Practical Physiology.) This, when compared with the rapidity with which electricity (464,000,000 yards), light (300,000,000), sound (3,485), or even a cannon ball (552 yards in a second) travels, is comparatively trifling. It is diminished by a low temperature (Helmholz), and by the electrotonic state (Von Bezold), and is increased in the motor nerves as the nerve approaches the muscle (Munk). A modification of the apparatus has enabled Schelske and Jaager to determine the time required for sensation and a subsequent act of volition. In one set of experiments, a person on receiving a slight electrical shock on the right side, immediately moved a spring key with his right hand, and on receiving a shock on the left side, moved another key with his left hand; and he knew beforehand on which side he was going to be stimulated, and therefore would have to answer. In another set of experiments, the side was not known beforehand, and the person, after having received the shock, had first to consider which side had been struck, and with which hand accordingly he had to act. The mean time occupied in the first case was equal to ·205 sec. in the second to ·272 sec. So that the difference of ·067 was obviously the time spent in the operation of the brain, required in the second, and not required in the first case. Hirsh determined that the difference in answering by the volition signal from sensations given through the eye was equal to ·077 of a second, and through the ear ·149 of a second. "It thus appears that 'quick as thought' is, after all, not so very quick."*

Sensation may be defined to be *the consciousness of an impression;* and that it may take place, it is necessary,—1st, That a stimulus should be applied to a sensitive nerve, which produces an impression ; 2d, That, in consequence of this impression, a something should be generated we designate an influence, which influence is conducted along the nerve to the hemispherical ganglion ; 3d, On arriving there, it calls into action that faculty of the mind called consciousness or perception, and sensation is the result. It follows that sensation may be lost by any circumstance which destroys the sensibility of the nerve to impressions ; which impedes the process of conducting the influence generated by these impressions ; or, lastly, which renders the mind unconscious of them. Illustrations of how sensation may be affected in all these ways must be familiar to every one, from circumstances influencing the ultimate extremity of a nerve, as on exposing the foot to cold ; from injury to the spinal cord, by which the communication with the brain is cut off ; or from the mind being inattentive, excited, or suspended.

The independent endowment of nerves is remarkably well illustrated by the fact, that whatever be the stimulus which calls their sensibility into action, the same result is occasioned. Mechanical, chemical, galvanic, or other *physical* stimuli, when applied to the course or to the extremities of a nerve, cause the very same results as may originate from suggestive ideas, perverted imagination, or other *psychical* stimuli. Thus a chemical irritant, galvanism, or pricking and pinching a nerve of motion, will cause convulsion or spasms of the muscles to which it is distributed. The same stimuli applied to a nerve of common sensation will cause pain, to the optic nerve flashes of light, to the auditory nerve ringing sounds, and to the tip of the tongue peculiar tastes. Again, we have had abundant opportunities of witnessing the fact, that suggestive ideas, or stimuli originating in the mind, induce similar effects on the muscles, give rise to pain or insensibility, and cause perversion of all the special senses. (See "Mono-ideism.")

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* Sir Du Bois Reymond's Lecture at the Royal Institution of Great Britain, April 13. 1866.

Motion is accomplished through the agency of muscles, which are endowed with a peculiar vital property called *contractility* (see p. 177), in the same way that nerve is endowed with the property of sensibility. Contractility may be called into action altogether independent of the nerves (Haller), but may also be excited by physical or psychical stimuli, operating through the nerves. *Physical* stimuli (as pricking, pinching, galvanism, &c.), applied to the extremities or course of a nerve, may cause convulsions of the parts to which the motor filaments are distributed directly, or they may induce combined movements in other parts of the body *diastaltically* (Marshall Hall),—that is, through the spinal cord. In this latter case the following series of actions take place :—1st, The influence of the impression is conducted to the spinal cord by the afferent or *esodic* filaments which enter the gray matter. 2d, A motor influence is transmitted outwards by one or more efferent or *exodic* nerves. 3d, This stimulates the contractility of the muscles to which the latter are distributed, and motion is the result. Lastly, Contractility may be called into action by *psychical* stimuli or mental acts,—such as by the will and by certain emotions. Integrity of the muscular structure alone is necessary for contractile movements ; but there must be also integrity of the spinal cord, for diastaltic or reflex movements ; and of the brain proper, for voluntary or emotional movements.

Thus, then, we may consider that the brain acting alone furnishes the conditions necessary for intelligence ; that the spinal cord furnishes the conditions essential for the co-operative movements necessary to the vital functions ; and that the brain, spinal cord, and nerves, acting together, furnish the conditions necessary for voluntary motion, and for sensation.

LAWS REGULATING MORBID ACTIONS OF THE NERVOUS SYSTEM.

1. *The peculiarity of the cranial circulation*, previously described (p. 220), shews how general or local congestions may occasion the most violent effects, without giving rise to struc-

tural lesion, or increasing the amount of fluid within the cranium. Thus all the symptoms of apoplexy followed by death may take place, and on *post-mortem* examination no change in the brain or its membranes be found. Such cases were called by Abercrombie, *simple apoplexy*. A young person receives distressing intelligence, and faints—that is, loses consciousness, sensation, and volition. This depends on weakness of the heart, causing venous cerebral congestion. The most violent convulsions and passions, associated or not with disorder of the mental functions, such as epilepsy, hydrophobia, tetanus, &c., leave no trace of their existence, and are often attributable to congestions, which, by increasing blood pressure in some parts of the cerebrum, and diminishing it in others, offers the only explanation of such phenomena.

2. *All the functions of the nervous system may be increased, perverted, or destroyed, according to the degree of stimulus or disease operating on its various parts.*—Thus, as a general rule, it may be said that a slight stimulus produces increased or perverted action; whilst the same stimulus, long continued or much augmented, causes loss of function. All the various stimuli, whether mechanical, chemical, electrical, or psychical, produce the same effects, and in different degrees. Circumstances influencing the heart's action, stimulating drinks or food, act in a like manner. Thus, if we take the effects of alcoholic drink for the purpose of illustration, we observe that, as regards combined movements, a slight amount causes increased vigour and activity in the muscular system. As the stimulus augments in intensity, we see irregular movements occasioned, staggering, and loss of control over the limbs. Lastly, when the stimulus is excessive, there is complete inability to move; and the power of doing so is temporarily annihilated. With regard to sensibility and sensation, we observe cephalagia, tingling, and heat of skin, *tinnitus aurium*, confusion of vision, *muscæ volitantes*, double sight, and lastly, complete insensibility and coma. As regards intelligence, we observe at first rapid flow of ideas, then confusion of mind, delirium, and, lastly, sopor and perfect unconsciousness. In the same manner, pressure, mechanical irritation, and the various organic diseases, produce augmented, perverted, or diminished function, according to the intensity of the stimulus applied, or amount of structure destroyed.

Then it has been shewn that excess or diminution of stimulus, too much or too little blood, very violent or very weak cardiac contractions, and plethora or extreme exhaustion, will, so far as the nervous functions are concerned, produce similar alterations of motion, sensation, and intelligence. Excessive hæmorrhage causes muscular weakness, convulsions, and loss of motor power, perversions of all the sensations, and, lastly, unconsciousness from syncope. Hence the general strength of the frame cannot be judged of by the nervous symptoms, although the treatment of these will be altogether different, according as the individual is robust or weak, has a full or small pulse, &c. These similar effects on the nervous centres, from apparently such opposite exciting causes, can only be explained by the peculiarity of the circulation previously noticed. A change of circulation within the cranium takes place, and whether arterial or venous congestion occurs, pressure on some portion of the organ is equally the result. The importance of paying attention to this point in the treatment must be obvious.

3. *The seat of the disease in the nervous system influences the nature of the phenomena or symptoms produced.*—As a general rule, it may be stated, that disease or injury of one side of the encephalon especially influences the opposite side of the body. It is said that some very striking exceptions have occurred to this rule ; but these, at any rate, are remarkably rare. Besides, it is probable that, inasmuch as extensive organic disease, if occurring slowly, may exist without producing symptoms ; whilst it is certain most important symptoms may be occasioned without organic disease, even these few exceptional cases are really not opposed to the general law. Then, as a general rule, it may be said that diseases of the brain proper are more especially connected with perversion and alteration of the intelligence ; whilst diseases of the cranial portion of the spinal cord and base of the cranium are more particularly evinced by alterations of sensation and motion. In the vertebral portion of the cord, the intensity of pain and of spasm, or want of conducting power, necessary to sensation and voluntary motion, indicates the amount to which the motor and sensitive fibres are affected. Further than this we can scarcely generalise with prudence.

The fatality of lesions affecting various parts of the nervous centres varies greatly. Thus the hemispheres may be extensively diseased, often without injury to life, or even permanent alteration of function. Convulsions and paralysis are the common results of disease of the ganglia in the cranial portion of the cord. The same results from lesion of the *pons Varolii.* But if the *medulla oblongata*, where the eighth pair originates, be affected, or injury to this centre itself occur, it is almost always immediately fatal.

4. *The rapidity or slowness with which the lesion occurs influences the phenomena or symptoms produced.*—It may be said, as a general rule, that a small lesion—for instance, a small hæmorrhagic extravasation—occurring suddenly, and with force, produces, even in the same situation, more violent effects than a very extensive organic disease which comes on slowly. This, however, will depend much upon the seat of the lesion. Very extraordinary cases are on record where large portions of the nervous centres have been much disorganised without producing anything like such violent symptoms as have been occasioned at other times by a small extravasation in the same place. Here, again, the nature of the circulation within the cranium offers the only explanation, for the encephalon must undergo a certain amount of pressure, if no time be allowed for it to adapt itself to a foreign body ; whereas any lesion coming on slowly, enables the amount of blood in the vessels to be diminished according to circumstances, whereby pressure is avoided.

5. *The various lesions and injuries of the nervous system produce phenomena similar in kind.*—The injuries which may be inflicted on the nervous system, as well as the morbid appearances discovered after death, are various. For instance, there may be an extravasation of blood, exudation of lymph, a softening, a cancerous tumour, or tubercular deposit, and yet they give rise to the same nervous phenomena, and are modified only by the circumstances formerly mentioned, of degree, seat, suddenness, &c. Certain nervous phenomena also are of a paroxysmal character, whilst the lesions supposed to contain them are stationary or slowly increasing. It follows that the effects cannot be ascribed to the nature of the lesions, but to something which they all have in common ; and this apparently may consist of—1st, Pressure, with or without organic change ; 2d, More or less destruction or disorganisation of nervous texture. Further, when we consider that the same nervous symptoms

arise from irregularities in the circulation; from increased as well as diminished action; sometimes when no appreciable change is found, as well as when disorganisation has occurred; the theory of local congestion to explain functional alterations of the nervous centres seems the most consistent with known facts. That such local congestions do frequently occur during life without leaving traces detectable after death, is certain; whilst the occurrence of molecular changes, or other hypothetical conditions which have been supposed to exist, have never yet been shewn to take place under any circumstances.

The following aphorisms will be found useful in endeavouring to reason correctly on the functions of the nervous system:

1. The brain proper is that portion of the encephalon situated above and to the outside of the *corpus callosum.*
2. The spinal cord is divided into a cranial and vertebral portion.
3. The gray matter evolves, and the white conducts, nervous power.
4. *Contractility* is the property peculiar to fibrous texture, whereby it is capable of shortening its fibres. Motion is of three kinds—*contractile*, dependent on muscle; *diastaltic*, dependent on muscle, nerve, and spinal cord; *voluntary*, dependent on muscle, nerve, spinal cord, and brain.
5. *Sensibility* is the property peculiar to nervous texture, whereby it is capable of receiving impressions and of transmitting the influences they produce. *Sensation* is the consciousness of such impressions.

Special Functions of the Nervous System.

On proceeding to determine more closely what are the special functions of the individual parts of the nervous system, we should never forget that the various ways in which they have been investigated have led to opposing results, and that such is the excessive difficulty of the inquiry, that we should be especially on our guard against specious hypotheses and unfounded theories. Anatomy, human and comparative—and more especially histology—have furnished us with many valuable facts; but it is not easy to determine what are the nervous ganglia or other parts in the lower animals which correspond with what exists in man; whilst erroneous interpretations as to the habits and motions of these creatures are too readily formed. Again, in making experiments on animals, it is often impossible to ascertain how far the shock of the operation, the flow of blood, or the destruction of other parts may vitiate the results. Lastly, an observation of the effects of disease often leaves us in doubt how far the organic mischief extends, and what phenomena may be rightly attributed to it, and what to the congestion of the blood vessels which accompany it. This last, however, is by far the most important means of research open to us ; and if to the result of pathological observation, a similar one is obtained from well-performed experiments, our views derived from either will be confirmed. If to this, histology reveals connections in structure that will warrant and bear out such conclusions, we may consider that every proof is given which conviction requires. It should be remembered, therefore, that such is the fallacy inherent in each individual method of research that little dependence can be placed upon it, and that at least two of these must be united to give probability to any given theory. The results of these four different methods of investigation must be known in order to draw correct conclusions.

Cerebrum.

Histological results.—On carefully examining a thin vertical section of the cerebral lobes prepared after the manner of Lockhart Clarke, and steeped in carmine, the white substance in the adult may be seen to be composed wholly of nerve tubes. These become more and more minute as they reach the gray matter of the convolutions, and are gradually lost in it. The layer of gray matter consists of a finely molecular substance, in which are imbedded minute nerve cells, varying in shape and size as they are traced from the circumference inwards. Externally, the cells are small, and associated with granules and naked nuclei. Internally, they are larger, circular, oval, and especially of a triangular form, sending off processes continuous with the nerve tubes. (See Plate XV. fig. 1.)

Experimental results.—The experiments of Flourens, Hertwig, Longet, and others, have shewn that on removing the cerebral lobes from birds, the mental faculties, including, of course, consciousness and volition, and therefore sensation and voluntary motion, are abolished, while the creature can stand when put on its legs, fly when thrown into the air, and walk when pushed.

Hertwig has kept pigeons in this condition for three months, deglutition and all other reflex acts being perfect, the mental faculties only absent. Longet and Dalton have recently maintained that sensation may exist without the cerebral lobes. The former says, when the cerebrum was removed from a pigeon, and a light suddenly brought near its eyes, there was contraction of the pupil, and even winking. Further, when a rotatory motion was given to the candle at such a distance that no heat could operate, the pigeon made a similar movement with its head. But of these facts I would observe that the pupil will contract on the application of light when the eye has been cut out of the head, and a sunflower follows the course of the sun. It cannot, therefore, be said that under such circumstances the eye and the flower possess sensation or can see.

Dalton's description of what occurs after removal of the cerebrum is as follows :—" The effect of this mutilation is simply to plunge the animal into a state of profound stupor, in which he is almost entirely inattentive to surrounding objects. The bird remains sitting motionless upon his perch or standing upon the ground, with the eyes closed and the head sunk between the shoulders. (See Plate XV. fig. 3.) The plumage is smooth and glossy, but is uniformly expanded by a kind of erection of the feathers, so that the body appears somewhat puffed out, and larger than natural. Occasionally the bird opens its eyes with a vacant stare, stretches its neck, perhaps shakes its bill once or twice, or smooths down the feathers upon its shoulders, and then relapses into its former apathetic condition. This state of immobility, however, is not accompanied by the loss of sight, of hearing, or of ordinary sensibility. All these functions remain, as well as that of voluntary motion. If a pistol be discharged behind the back of the animal, he at once opens his eyes, moves his head half round, and gives evident signs of having heard the report ; but he immediately becomes quiet again, and pays no further attention to it. Sight is also retained, since the bird will sometimes fix its eye on a particular object, and watch it for several seconds together. Ordinary sensation also remains after removal of the hemispheres, together with voluntary motion. If the foot be pinched with a pair of forceps, the bird becomes partially aroused, moves uneasily once or twice from side to side, and is evidently annoyed at the irritation."

From these observed facts, which are strictly accurate, Dalton concludes that " the animal is still capable, after removal of the hemispheres, of receiving sensations from external objects. But these sensations appear to make upon him no lasting impression. He is incapable of connecting with his perceptions any distinct succession of his ideas. He hears, for example, the report of a pistol, but he is not alarmed by it ; for the sound, though distinctly enough perceived, does not suggest any idea of danger or injury. There is accordingly no power of forming mental associations, nor of perceiving the relation between external objects. The memory, more particularly, is altogether destroyed, and the recollection of sensations is not retained from one moment to another. The limbs and muscles are still under the control of the will, but the will itself is inactive, because apparently it lacks its usual mental stimulus and direction."

I think the facts may be interpreted differently and more correctly. The turning round of the animal's head on the explosion of a pistol, and many other movements, may be altogether reflex, dependent on irritations communicated to the cranial portion of the spinal cord through the tympanum. Again, that the pigeon should open its eyes with a vacant stare, or apparently fix them on an object, is no proof of sight. We constantly do these things ourselves with the brain entire, and see nothing. Lastly, that the limbs and muscles are under the control of the will, while the will is inactive, appears to be contradictory language. One of the most active operations of the will is to direct motion ; and to say of a bird which flies away on the production of the slightest noise in health, but does not move on the discharge of a pistol, that in the latter case its limbs and muscles are still under the control of the will, appears to be a most unfounded conclusion. The truth evidently is, that there is no will, no sensation in such a case, any more than there is in a sensitive plant, which shrinks on being touched, but which surely cannot be said to exercise either the one mental faculty or the other.

Pathological results.—The general results of pathological and clinical observation confirm those obtained by experiment. Thus disease of the membranes, especially meningitis over the hemispheres, occasion delirium, which passes into coma. If it be limited to the base or *medulla oblongata,* it causes convulsions and paralysis, or lesions of motion.

Many remarkable cases of injury the human brain has sustained have been published, which shew that the hemispheres are in themselves insensible. If universally diseased, the result has been, as in the lower animals, complete loss of mind, volition, and sensation. The same occurs if general pressure is applied, as in cases of fracture of the cranium with depression of bone. Many examples, however, are known where partial destruction of, or pressure on, the cerebral lobes has not permanently injured the intelligence. Thus, 1. A gun exploded in the hands of a man, æt. 22, and a piece of iron entered the frontal bone, and destroyed a considerable portion of *both* anterior and cerebral lobes. From this injury he recovered without any perceptible injury of mind.* 2. A boy, æt. 11, was kicked by a horse, so as to occasion fracture of the *os frontis*, and pultaceous softening of *both* anterior lobes, as was proved by post-mortem examination. He lived forty-three days after the accident, and was perfectly intelligent up to one hour of his death.† 3. An artist had spectral illusions and blindness for years, but was quite intelligent till he was seized with apoplexy, of which he died. *Both* anterior lobes of the brain were destroyed by a mass of hydatid cysts.‡ 4. A wig maker, æt. 60, was very loquacious, but otherwise perfectly intelligent, and died suddenly in the Charité Hospital of Paris. On post-mortem examination, *both* anterior lobes of the brain were the seat of a schirrous tumour.§

Thus partial destruction of a considerable portion of the cerebral lobes does not necessarily destroy intelligence, nor does partial destruction of the white matter necessarily interfere with its conducting properties. Then there are many cases of large chronic abscesses or of pultaceous softenings in the white matter of one or both cerebral lobes, in which there has been no paralysis, and no impairment of sensation nor voluntary motion. In all such cases, some of the conducting tubules have escaped the morbid action, and have been sufficient to maintain the transmitting power. In no case, however, where the entire gray matter of the convolutions nor of the white matter of the hemispheres have been destroyed, has the intelligence or conducting power remained uninjured.

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* Edinb. Med. and Surg. Journal, vol. xliii. p. 292.

† American Medical Intelligencer. April 1. 1837.

‡ Medico-Chirurgical Review, vol. xxiv. p. 202.

§ Bulletin de l'Académie de Médicine, vol. xxx. p. 799, 1865.

There can be no doubt that the relation between the molecular, nuclear, and cell elements of the hemispherical ganglion, as the instrument of mind, must be most important ; and yet I am not acquainted with any one, who, having first qualified himself for the task by a prolonged and careful study of histology, has investigated, on a sufficiently extensive scale, the brain in cases of insanity. Psychologists content themselves with repeating well-known clinical observations, with the ordinary morbid anatomy or density of the brain, and with the metaphysical speculations which have been pushed as far as, if not further than, human intellect can carry them. Need we feel surprised that the true pathology of insanity is unknown ? What we desiderate is a careful scrutiny of the organ. Hitherto the difficulties of such an investigation have been insurmountable, in consequence of our imperfect methods of research. But let any one possessing a competent knowledge of histology, and the use of our best microscopes, with the opportunities our large asylums offer, only now dedicate himself to the task, and he may be assured, that while extending the bounds of science, he will certainly obtain an amount of fame and honour that few can hope to arrive at. The molecules on which muscular contractility depends are, as we have seen, visible molecules, and so I believe are those in the hemispherical ganglion, so essentially connected with the functions of the brain.

From the various facts now known, I think it may be concluded that the cortical substance of the cerebral lobes furnishes those conditions which are necessary for thought, including all mental operations, sensation and volition. Further than this we are not warranted in going, for the facts which establish these great conclusions entirely negative, as we shall see, all those theories which have been advanced having for their object a localisation of the different faculties into which the mind has been arbitrarily divided.

The Mental Faculties.—When we endeavour to determine these, and separate the reasoning powers from instinctive actions, the difficulty of the inquiry seems at first to be overwhelming. To analyse the intricate combinations of our own minds is a difficult task ; but how much more laborious is it to study the variations in the minds of others, and to investigate the habits of the countless tribes of animals with the view of distinguishing which depend on reason, and which on blind instinct! The attempts of metaphysicians in this direction are not satisfactory. At the commencement of the present century, Dugald Stewart considered the mental faculties to be Consciousness, Perception, Attention, Conception, Abstraction, Association of Ideas, Memory, Imagination, and Judgment or Reasoning. To these he added the Affections, Desires, Self-love, and the Moral Faculty.

His successor in this University, Dr Thomas Brown, divided Mental Phenomena (1822) into two great divisions, viz., the external affections and internal affections. The external comprehend all our sensations, and the internal are divided into two branches, the one intellectual, the other emotional. Under the intellectual states we have simple and relative suggestions, and under emotional states we have all the passions and desires. This classification is more comprehensive than that of Stewart's, recognising, as it does, however dimly, the necessity of conjoining physiological facts with metaphysics.

In recent times it has been maintained that the study of mind ought not to be considered as a branch of transcendental philosophy, but as a positive science, called Psychology; and those who have thus cultivated it, instead of multiplying the mental faculties, have contracted them under three heads, viz., Intellect, Sensation, and Volition. The various modes of considering and applying these faculties by Schelling, Hegel, and others in Germany, by Royer Collard, Cousin, and others in France, and by Hamilton, Mill, Bain, Morrell, Maudesley, and others in this country, constitute a wide field of knowledge, which occupies two chairs in this University under the names of Moral Philosophy and Logic. I can only briefly give a summary of the results. (For the relation existing between mind and brain, see p. 180.)

At present, then, we may conveniently consider that the mental faculties are of three kinds—1st, Purely intellectual—we think; 2d, The sensations—we feel; 3d, Volition—we will, we determine.

1. *Intellect.*—Of the intellectual faculties there is a general or predominant one, viz., *Consciousness.* It is the *ego* or idea of our own existence, and which, influenced in various ways, causes the other mental faculties. Thus, if directed to the present, it is *Perception;* if it recals the past, it is *Memory;* if it suggests the ideal, it is *Imagination;* if applied to thought synthetically, it is *Generalization*—if analytically, it is *Reason-*

ing; if it originate ideas intuitively, it is *Original Conception.*

2. *The Sensations* are of two kinds, physical and mental; that is, we can feel pain or pleasure from physical agents or from mental operations. The physical sensations are *Touch*, *Taste*, *Smell*, *Hearing*, *Sight*, and the *Muscular sense*, or *sense of weight.* The mental sensations are *Hope*, *Fear*, *Grief*, *Pride*, *Love*, *Hatred*, *Desire*, *Aversion*, *Joy*, *Sorrow*, *Despair*, *Audacity*, *Courage*, &c. To these may be added *Self-love*, or *Vanity*, and the *Moral Faculty*—a feeling of being right or wrong.

3. *Volition.*—Sensation, as we have previously seen, is the consciousness of an impression, and the same relation that the influence has to consciousness volition has to sensation. To will, there must be an object, physical or mental. Thus will, directed to the muscles, causes *voluntary motion;* if to sensation, *attention;* if to thought, *abstraction*, or concentration of ideas.

Phrenology.—Gall and Spurzheim have divided mind into thirty-three faculties, to which Mr Combe added two more, making thirty-five in all. These are—1st, *Amativeness;* 2d, *Philoprogenitiveness*, or love of offspring; 3d, *Concentrativeness*, or the power of continuing impressions and ideas; 4th, *Adhesiveness*, or the desire to attach ourselves to persons or objects; 5th, *Combativeness*, or the inclination to fight and be embroiled in contentions; 6th, *Destructiveness*, or the desire of destroying life; 7th, *Constructiveness*, or a disposition to apply oneself to the mechanical arts; 8th, *Covetousness*, or the desire to covet, to amass, or acquire; 9th, *Secretiveness*, to conceal; 10th, *Self-Esteem*, or self-love; 11th, *Love of Approbation*, or the pleasure we derive from the commendations we receive from others; 12th, *Cautiousness;* 13th, *Benevolence*, or meekness and gentleness of disposition; 14th, *Veneration*, by which we worship the Deity and material objects; 15th, *Hope;* 16th, *Ideality*, or the poetical disposition; 17th, the faculty of *Conscientiousness*, or of justice and equality; 18th, *Determinativeness*, or firmness of character or purpose; 19th, *Individuality*, or the power we possess of knowing external things; 20th, *Form*, by which we take cognisance of the forms of external objects; 21st, *Size*, that power which seizes hold of dimensions; 22d, *Weight*, that faculty by which we estimate weight, density, resistance, &c.; 23d, *Colour*, the faculty of perceiving colours; 24th, *Space* or *Locality*, the power of local memory; 25th, *Order*, or a love of methodical arrangement ; 26th, *Time*, or the faculty which enters into speculations on duration ; 27th, *Number*, or the power of calculation ; 28th, *Tune*, or the perception of musical tone ; 29th, *Language*, the faculty by which we learn artificial signs ; 30th, *Comparison*, by which we recognise differences, analogies, similitudes, &c. ; 31st, *Causality*, that power which directs our attention to the causes of things ; 32d, *Wit*, the faculty of jesting, raillery, mocking, &c. ; 33d, *Imitation*, the power of imitating sounds, gestures, manners, &c. These are the several faculties of mind laid down by Drs Gall and Spurzheim ; but to this catalogue Mr Combe has added two others,—34th, *Wonder*, or that which relates to the marvellous, supernatural, &c. ; and 35th, *Eventuality*, or that which takes cognisance of changes, events, and active phenomena.

The objections to this division of the mental faculties are,—1st, Its complexity ; and according to the phrenological system, one faculty is considerably influenced by others ; so that compound characters may be easily manufactured at will, and thus numerous sources of fallacy thrown open. 2d, It is redundant in some faculties, and deficient in others. It is redundant, for instance, in having two organs for Form and Size, for Combativeness and Destructiveness, for Causality and Concentrativeness. Each of these two, if not identical, are, at all events, closely allied. It is deficient in having no such faculties as Memory, Reasoning, and Judgment, which every man is conscious he possesses. But it is said that every organ has a power of remembering, reasoning, and judging ; so that there are other faculties which govern or attend upon all the thirty-five organs. There are also obvious deficiencies in the propensities or instincts ; for mankind not only love, steal, fight, kill, secrete, and build, but run, swim, walk, talk, sing, learn, and so on, which have no place in the phrenological system. Perhaps there is no instinct so strong in man and animals as that of self-preservation, and yet this has no organ ascribed to it by the phrenologists. As a philosophical and metaphysical system of the mental faculties, therefore, the classifications of Stewart and Brown seem to us greatly superior, especially in all the higher properties of the intellect ; although, so far as the instincts and passions are concerned, they are, perhaps, inferior.

The individual mental faculties cannot be localised.—If our knowledge of what the faculties of the mind really are, and how they should be divided, is so imperfect, it may appear unnecessary to attempt to determine in what part of the brain each is situated. As might be expected, all such efforts have failed. That the brain furnishes the conditions necessary for the evolution and manifestation of mind, we have seen, is established ; and that the gray matter originates, whilst the white matter conducts, the influences generated, we have also shewn to be highly probable. But we have no facts which point out that Memory, Consciousness, Judgment, Reasoning, or similar faculties belong to one part of the cerebral convolutions more than to another. Gall and his followers have localised all the thirty-five faculties into which they have divided the mind. He observed that certain individuals who displayed mental powers, moral feelings, or particular propensities, had a fulness or prominence in a certain part of the anterior, middle, or posterior third of the cranium. By paying attention to the principal characteristics of remarkable men, and the living habits of animals, he found that this fulness or prominence coincided in a number of cases ; and he concluded from this that the function of brain which existed below the prominence was the organ giving rise to the characteristic faculty. He then sought to confirm his theory by anatomy, physiology, and pathology ; and he and his disciples have accumulated an immense number of these coincidences, which they believe sufficient to establish the phrenological theory.

But, proceeding on the principles which the phrenologists themselves have laid down, it is easy to shew that the exceptions are as numerous as the coincidences ; whilst the other modes of inquiry to which we have alluded,—namely, anatomy, the results of experiments on living animals, and the observations of the symptoms of disease as compared with the appearances presented after death,—not only give no support, but are directly opposed to the views of Gall. Thus some remarkable skulls in the Museum of the University of Edinburgh are, on the principles of the phrenologists themselves, entirely opposed to their doctrines. Of these, among many, we would point to the skulls of Burke (Plate XV. fig. 5), Pepé (Fig. 6), and Haggart (Fig. 7),—all three remarkable murderers, with Destructiveness small ; and the last a most dexterous thief, with Acquisitiveness small. The flattened appearance of the organ of Destructiveness in these skulls contrasts remarkably with the ordinary type of Saxon skull (Fig. 8). Anatomy proves that, while the lower vertebrate animals possess the anterior and middle lobes of the brain well developed, which are said to be the seat of the intellectual faculties and moral sentiments, they are deficient in those parts where Love of Offspring, Adhesiveness, Destructiveness, and Combativeness are found,—facts wholly incompatible with the theory of Gall. In the same manner, the great majority of facts derived from physiological and pathological research give no support to phrenology. We have previously seen how several cases prove that both anterior lobes of the brain, where the phrenologists have placed the higher mental faculties, may be completely destroyed without affecting the intellect. (See p. 297.) Although, therefore, this doctrine is unquestionably founded upon a large number of data, it cannot lay claim to a correct localisation of the mental faculties in any way superior to other systems, which, like those of Camper and Lavater, have been advanced by ingenious men, have excited attention for a season, and been ultimately abandoned as inconsistent with the present state of our knowledge. The names of Gall, Spurzheim, and Combe, notwithstanding, ought ever to be registered among those whose labours have greatly contributed to advance our knowledge of the physiology of the brain.

CEREBELLUM.

Histological results.—The ganglionic surface of the cerebellum is structurally altogether unlike that of the cerebrum. On looking at a well-made vertical section of the former, prepared after the method of Lockhart Clarke, and steeped in carmine, under a magnifying power of 25 diameters, the fine tubular substance in the centre is seen to be bounded externally by a granular layer, outside which is a row of nerve cells with branched processes gradually terminating towards the margin of the exterior layer, which is finely molecular. On increasing the magnifying power to 250 diameters, we see more distinctly the relation of these various parts to one another, and recognise in the interior of each granule an included rounded body. (See Plate XV. fig. 2.) According to Gerlach, these corpuscles are united to one another by a slender filament, which he has figured in a hypothetical diagram. Although such an appearance as he has imagined cannot be discovered in the natural structure, I have seen the tubes running between the granules. and traced them to the external margin of the granular layer. The external layer is the structure which demands the greatest attention. (Fig. 2, *a.*) It is composed essentially of a finely molecular mass, containing numerous capillaries derived from the vessels of the meninges. Large ganglionic cells external to the granular layer send off branching processes towards the circumference, which are gradually lost as they proceed outwards. Both in the external, as well as in the internal layers, the basis of the texture is evidently *molecular*—a fact which hitherto has received far too little attention.

Experimental results.—If the cerebellum be removed gradually from a pigeon in successive slices, there is progressive circumscription of the locomotive actions. On taking away only the upper layer there is some weakness and a hesitation in its gait. When the sections have reached the middle of the organ, the animal staggers much, and assists itself in walking with its wings. The sections being continued further, it is no longer able to preserve its equilibrium without the assistance of its wings and tail ; its attempts to fly or walk resemble the fruitless efforts of a nestling, and the slightest touch knocks it over. At last, when the whole cerebellum is removed, it cannot support itself even with the aid of its wings and tail ; it makes violent efforts to rise, but only rolls up and down ; then, fatigued with struggling, it remains for a few seconds at rest on its back or abdomen, and then again commences its vain struggles to rise and walk. Yet all the while its sight and hearing are perfect. The slightest noise, threat, or stimulus, at once renews its contortions, which have not the slightest appearance of convulsions. (Plate XV. fig. 4.) These effects, first described by Flourens, have been confirmed by all experimenters, and occur in all animals. The results contrast very strongly with those of the much more severe operation of removing the cerebral lobes. " Take two pigeons," says Longet ; " from one remove completely the cerebral lobes, and from the other only half the cerebellum ; the next day the first will be firm upon its feet, the second will exhibit the unsteady and uncertain gait of drunkenness."

These facts induced Flourens to consider the cerebellum as the co-ordinator of motion, in which view he was supported by the late Dr Todd and others. Foville, on the other hand, supposed it to be the seat of sensation, and argued that, as it is by means of this function that we regulate muscular motion, so, when it is destroyed, the faculty of perceiving the movements being lost, we cannot answer for their precision or duration. That it should be the seat of sensation generally is disproved by the fact that the animal is evidently conscious of impressions after its removal ; but that it should be the organ of that peculiar sense, which has been variously called "muscular sense," "sense of resistance," and "sense of weight," is very probable. Accordingly we find that Professor Lussana, of Parma, has brought together all the arguments which exist as to this matter, along with numerous original observations, confirmatory of the view that the cerebellum does indeed regulate motion, but in consequence of its being the seat of the muscular sense.*

It has been suggested by Carpenter and Dunn that the *corpus dentatum* in the cerebellum is the ganglion which is connected with this sense, a view rendered improbable by Brown Séquard's analysis of cases where the organ was diseased. I submit that the function is seated in the external layers of grey matter rather than in the corpus dentatum—a theory to which the same objections do not apply. Mind frequently remains when portions of the hemispherical ganglion are injured, although we know of no instance in which, where the whole of it has been diseased, intellect has been preserved. So the co-ordinating motor power may remain when parts only of the cerebellar leaflets are destroyed, but is certainly lost when the whole gray matter is diseased. That the cerebellum, therefore, is connected with a special sense, through which it influences the co-ordinate action of the muscles, is a doctrine worthy the attention of physiologists. Its external layers of grey matter, constituting a complex ganglionic structure, has probably the same relation to the muscular sense as the hemispherical ganglion has to sensation in general.

Pathological results.—Diseases of the cerebellum, such as extravasations of blood into its substance, softenings, tumours, tubercular deposits, although they generally have as a symptom paralysis or convulsions, these are often well marked, and are very violent from apparently trifling lesions, and are as often slight when the whole or greater portion of the organ has been completely disorganised. The result of pathological inquiry throws no light upon any of the proposed functions of the cerebellum. In two remarkable cases where it was atrophied,* although there were epileptic and other convulsions, co-ordination of motion existed in the intervals. According to Gall, the cerebellum is the seat of the sexual instinct. This was not only present but excessive in both the cases referred to, shewing that diminution in the size of the organ did not produce diminution of the alleged function. In a singular cranium in our University Museum, the prominence over the organ of amativeness is remarkable (Plate XV. fig. 9), but on dissection the cerebellum was found to be normal, the enlargement being caused by thickening of the bone, and great distension of the *Torcular Herophili*.

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* Journ. de Physiologie. Tom. vi. 1863.

Corpora Striata and Optic Thalami.

These parts of the encephalon consist of masses of ganglionic matter differently arranged, connected with the spinal cord below and the cerebrum above. The corpus striatum is in front of the optic thalamus, but a portion of its substance goes backwards and over it. This intimate relation of the two ganglia renders it difficult to experiment upon one without injuring the other. In the same way, disease of one is liable to influence the other, and in either case hemiplegia on the opposite side of the body is the general result. It follows that as yet we have no means of determining with certainty the functions of each ganglion, although it is probable that the corpora striata are connected with voluntary combined movements, and the optic thalami with sensation and with the sense of sight, but not exclusively so.

Dr Todd says of these bodies :—" The corpora striata and anterior horns are centres of motion ; the optic thalami and posterior horns are centres of sensation. The anterior pyramids connect the former ; the olivary columns, and perhaps some fibres of the anterior pyramids, the latter." He further argues " that the intimate connection of sensation and motion, whereby sensation becomes a frequent exciter of motion, and voluntary motion is always, in a state of health, attended with sensation, would *à priori* lead us to look for the respective centres of these two great faculties, not only in juxtaposition, but in union, at least as intimate as that which exists between the corpus striatum and optic thalamus, or between the anterior and the posterior horns of the spinal gray matter." That motion and sensation are intimately connected with these bodies, there can be no doubt, but that volition or sensation resides in them, or have their centres there, is opposed to all we know of the nature of volition and sensation, as well as to the facts connected with the cerebral lobes previously noticed. (See pp. 296, 297.)

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* By Combette, Cruvveilhier's Anat. Patholog. Liv. xv. Plate V. ; by Hyde Salter, Trans. of Lond. Patholog. Soc., vol. iv. p. 31.

Corpora Quadrigemina.

These ganglia, from their intimate connection with the optic nerves, have also been called *optic tubercles*, and been supposed to have some special relation to the sense of vision. Flourens determined that destruction of these on one side was followed by loss of sight on the opposite side, and that their removal on both sides deprived the animal of vision, without affecting the locomotive or intellectual powers, and leaving all sensibility, except to light, unaffected. Their total removal also paralysed both irides. Similar results have followed disease of these bodies, but it must be remembered that like effects have followed lesions of the optic tracts, of the thalami, of the cerebellum, and indeed of other parts of the brain and medulla oblongata. We cannot, therefore, suppose them to be exclusive centres of the sense of vision, or of those movements in the irides which are so necessary to sight, as Flourens supposed.

Rotatory and other convulsive movements.—When injuries of these tubercles are deep, so as to reach the medulla oblongata, with which they are intimately connected, general convulsive movements are produced. If the injury is only on one side, the opposite side of the body only is affected. Sometimes the animal rolls round its body towards the injured side. Similar turnings were produced by Magendie on cutting across the crus cerebelli, but were much quicker, the animal often making sixty revolutions in a minute. On puncturing the corpora quadrigemina and the pons Varolii with a pin, on the left side, Brown Séquard found that the right eye was convulsed, while the other was normal. There was also turning similar to what is often seen practised in the *manége.* The animal moves sideways, and describes a circle, with its body forming part of its radius, the head at the circumference, and the tail towards the centre of the circle. According to Magendie, certain injuries to the cerebellum cause the animal to push itself backwards, whilst injuries to the corpora striata oblige it to rush forwards. Turning movements have been induced by Flourens, after injuring the semicircular canals of the ear in birds. Longet has caused them in pigeons, by evacuating the humour of the eye. Similar convulsions have occasionally been observed in man as the result of disease, especially at the commencement of epileptic attacks. These remarkable movements, therefore, are probably occasioned by irritations and injuries which, by producing paralysis in some muscles, and convulsive contractions in others, oblige the animal to move in certain directions. Vertigo and partial blindness, however caused, may assist in their production.

PONS VAROLII AND MEDULLA OBLONGATA.

These portions of the encephalon possess the same function as the spinal cord, with the addition of being more essential to life, on account of their being the centres (especially the latter) which furnish the necessary power for maintaining the co-ordinate movements of respiration and deglutition. It is by arresting respiration, and paralysing the functions of the important organs to which the *vagi* nerves are distributed, that sudden injury to the *medulla oblongata* proves so rapidly fatal. Here also occurs that decussation of the anterior and middle columns of the cord to which is attributable the crossed action of lesions in the cerebral lobes—apoplectic extravasations, softenings, &c., in the right cerebral hemisphere, causing hemiplegia of the left side, and *vice versa.*

Destruction of the medulla oblongata in the hands of all experimenters has caused sudden death, but removal of the entire brain and cranial portion of the cord above this centre does not do so. The vertebral portion of the cord below may also be removed up to the origin of the phrenic nerve, without destruction to life. In amphibia these two experiments have been combined, and yet the animal will continue to breathe, and life be maintained. But when the medulla oblongata is injured, respiration and life at once cease. Hence the humane efforts of the hangman in this country to cause dislocation of the first or second cervical vertebra, so as to cause immediate death.

THE SPINAL CORD.

Histological results.—The spinal cord has two portions—a cranial and a vertebral. The former consists of a chain of ganglia more or less connected with one another, as well as with the cerebrum above and the vertebral part of the cord below; the latter is composed of two lateral halves divided by an anterior and posterior fissure. Each lateral half is subdivided into three columns—an anterior, middle, and posterior—by the two cornua of the central mass of gray matter, in which are numerous multipolar ganglionic cells. Through the centre runs the spinal canal, lined with columnar epithelium. The white matter of the lateral columns is composed of tubes, which, as shewn by Lockhart Clarke, on being traced inwards from the spinal nerves, join the ganglionic cells in the gray matter, and, through them, keep up a communication—1st, with the opposite lateral columns; 2d, with the cerebrum; and 3d, with the anterior and posterior roots of the nerves. (Plate XVI. fig. 2.) A transverse section of the tubes of the cord, shewing the axis cylinder, and white substance of Schwann, is given Plate V. figs. 21, 22. The multipolar cells, which embedded in molecular matter, constitute the gray substance of the cord, are similar to the one represented Plate III. fig. 28, *e*.

Experimental results.—Sir Charles Bell distinctly proved by experiment that the anterior roots of the spinal nerves were motor, and that the posterior roots were sensitive. On dividing the former in a living animal, voluntary motion of the parts to which it was distributed was lost; on dividing the latter, pricking or injury to those parts caused no sensation. On irritating the lower cut end of the anterior root, convulsion was produced; on irritating the upper end of the posterior root, pain. He also made the discovery that certain cerebral nerves were motor throughout their course, while others were wholly sensitive. These he called nerves of motion and of sensation, and when the two were combined in a single nerve, it was called a mixed nerve or senso-motory. His dissections led him to conclude that the motor nerves and motor roots of the spinal nerves were connected with the anterior column of the spinal cord, whilst the nerves of sensation and posterior roots of the spinal nerves were continuous with the posterior columns. He himself never experimented on the cord, but those who have done so, especially Longet and Van Deen, were induced to conclude that division of the anterior and posterior columns respectively, induced paralysis of motion and sensation ; and irritating them occasioned convulsion and pain. In these experiments, however, not only the anterior and posterior columns, but the middle columns and gray cornua were injured. Stilling divided the anterior column down to the gray matter, without causing paralysis of motion, and Brown Séquard, on dividing the posterior column only, which he did with a knife made for the purpose, found sensibility in the lower extremities, and pain, on irritation, to be increased. In either case, to cause paralysis of motion or of sensation, it was necessary to extend the incision into the grey matter. If two sections be made, however, midway between neighbouring spinal nerve roots, then conduction between the parts above and below the sections is cut off. (See Plate XV. fig. 12, *d*.) The explanation of this is to be found in the course taken by the nerve tubes, as shewn by Lockhart Clarke, which so diverge from one another, on passing into the cord, that no one transverse section of the column can divide them, although two at a certain distance from one another may (Fig. 12, *s*). In the same manner, two incisions, at right angles to one another, dividing the white substance and grey matter, completely destroy the power of transmission (Fig. 12, *b*). Thus histological research and experimental investigation support one another, and the two have now demonstrated that the conducting nerve tubes of the spinal roots of the nerves communicate through the gray matter of the cord, not only with the brain and the two sides of the body, but with each other.

These facts have served also to explain more fully the nature of those actions variously denominated automatic, reflex, and diastaltic, for the true knowledge of which we are indebted to the labours of Marshall Hall. It is now clear that the influences excited by irritation of nerves run continuously through the cord in certain directions, now communicating with muscles to produce spasms, and now with the glands and vessels to produce secretion and vaso-motor action, and this without any necessary connection with the brain, and, therefore, without sensation.

Reflex or diastaltic actions.—Numerous combined muscular actions may go on independent of volition or sensation, and even when the brain is removed. These depend on influences originating in physical irritations applied to an incident nerve, which are conducted through the spinal cord, and from it by excident nerves to the muscles, the contractility of which is thereby excited. The character of these movements gave rise to the idea that they were connected with sensation, and indicated pain. Thus, decapitated animals may be seen to struggle exactly as they would do were the brain entire. They appear to avoid the particular injury, push the irritating instrument away with their paws, and writhe as if in agony ; so that it is exceedingly difficult for a spectator to convince himself that they are not suffering, and that such motions are not connected with sensation. But we have previously seen, and the slightest analysis of our own sensations and mental operations will soon convince us, that sensation is the *consciousness* of an impression. If, then, the same sensitive and motor phenomena are produced independently of brain as when it is present, we must either believe that consciousness resides in the spinal marrow, and that, therefore, they are connected with sensation, or that it resides in the brain, in which case they must be independent of sensation. The former was the notion of Whytt, Haller, Le Gallois, Prochaska, and others, who connected these spinal movements with a so-called *sensorium commune.* Indeed, there is but one of these writers who reasoned correctly on this point, viz., Sir Gilbert Blane, who says, referring to a decapitated animal, " When the head is cut off, its irritability remains, as appears by the motion of the ears when pricked or touched by a hot wire, and as the extremities are also irritable, it will not be said that consciousness and sensation exist in two separated portions of the same body. Nor can it be admitted that sensibility and consciousness may remain in the head after separation ; for, if mere compression of the carotid arteries abolishes sensation and thought, by interrupting the circulation in the brain, how much more must the superior violence of decapitation have this effect." But, whilst Sir Gilbert Blane had a clear idea that these motions were independent of consciousness, he had no notion of their reflex character. On the other hand, this reflex function did occur to Prochaska, who, however, connected it with a *sensorium commune,* a term used by Descartes, Haller, Whytt, and others, to express the seat of sensation, which was placed by various writers in different parts of the nervous system. It was Dr Marshall Hall who first clearly separated these functions from cerebral or mental acts, and placed them altogether in the spinal cord. He pointed out that they were independent of mind, and, *therefore*, not connected with sensation. He classified them by themselves, under the name of reflex, excito-motory, or diastaltic actions; described the laws by which they are governed, and their universal application to the pathology and diagnosis of disease. We have previously seen (p. 289) that all such actions require a centre with incident and excident nerves communicating with it, although the exact relation of these, as explanatory of individual diastaltic movements, has not yet been determined.

As examples of diastaltic, or purely spinal motions, may be enumerated,—1st, Those constantly going on in the eyelids when any object approaches them, as in *winking*, in which case the incident nerve is the palpebral branch of the fifth, and the excident the orbicular branch of the seventh pair of nerves. 2d, The *closure of the larynx* in every act of deglutition, and in every effort to vomit, and as occurs on the contact of a drop of water or a crumb of bread, &c., when the incident nerve is the superior, and the excident the inferior laryngeal. 3d, The various movements associated in the act of *respiration*, in which the incident nerves are the sensitive portions of the fifth pair, of the pneumo-gastric and spinal nerves; while the excident are the spinal accessory and motor branches of the intercostal diaphragmatic, and lower spinal. 4th, The different actions associated in the act of *deglutition*, including those that occur in the pharynx, œsophagus, and the cardiac orifice of the stomach. The incident nerves are united with the excident in the pharyngeal, œsophageal, and cardiac portions of the pneumo-gastric. 5th, Numerous actions connected with the outlets of the body, as in *defœcation* and *expulsion* from the urinary and generative organs, in which the incident and excident nerves are united in the branches of the spinal nerves. 6th, The *movements of the fœtus* in utero. 7th, Numerous complex actions, acquired at one period, and performed afterwards automatically, without exercise of mind, such as *walking*, *singing*, *playing certain pieces of music on various instruments*, &c. 8th, *Instinctive actions of various animals*, as the flying of migratory birds, building their nests, construction of the honey-comb, &c. 9th, All the spasmodic and convulsive actions of the body, including *vomiting*, *choking* from the presence of a foreign body in the larnyx or pharynx, *nervous twitching* of the limbs, *con-*

vulsions of parts of the whole body in chorea, hysteria, epilepsy, and rigid spasms of tetanus, &c. In these four last kinds of actions, the sensitive nerves of various parts of the body are the incident, and the motor the excident nerves.

These diastaltic actions, though spinal and independent of mind, may, to a certain extent, be controlled by the will. Thus the sudden contact of hot or cold bodies to the skin, the prick of a pin, &c., if unexpected, will cause starting ; but if a resolution be formed not to do so, this effect may be prevented. This influence is exercised over different muscles in different degrees, and it varies in persons from constitutional and unknown causes. Other spinal actions apparently require the co-operation of the mind, such as *coughing*, *sneezing*, *laughing*, *sobbing*, *yawning*, and *hiccough*. In these cases it frequently happens that the most determined effort of the will fails to control them ; whilst arresting or withdrawing the attention, checks them at once. Hence we have one class of motions purely voluntary, and another, partly voluntary and partly spinal, such as coughing, laughing, sneezing, &c., which it is difficult to conceive being produced without a certain mental effort. Then we have a class of motions altogether involuntary, wholly spinal, which may be carried on for a certain time in a decapitated animal.

Pathological results.—Many cases have been published where no sensation has resulted from the application of the strongest stimuli to certain parts of the body, yet where voluntary motion in these parts has continued. Thus Mr Reid relates a case * where the sentient power was annihilated over the whole surface of the body, while the power of motion, though impaired, was so entire as to enable him to use his hands in carving his food, in writing, in holding the reins when on horseback, &c. Mr Liston removed one of his metatarsal bones which was carious, the operation giving him no pain whatever. Loss of voluntary motion has also been known to take place alone without influencing sensibility, but this is much more rare. A few cases are known where both these lesions have occurred in one person. Thus Dr H. Ley speaks of a woman who, after delivery, had defective sensibility on one side, and loss of motion on the other. She could hold her child to one breast as long as she looked at it, but on the attention being removed, the child was in danger of falling; on this side she could not feel the application of the child's mouth to the nipple, though she could see it sucking. On the other side feeling was perfect, but she was unable to hold the child to the breast.* Dr Bright gives a similar case,† and Andral mentions one of a man who had the right side of his face without sensibility, and the left without motion. In the great majority of cases, both motion and sensation are affected together, and the former suffers most. On recovery, sensibility is restored first, and motion afterwards.

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* Edin. Med. and Surg. Journal, vol. xxxi. p 292.

It has long been a matter of observation, that disease on one side of the brain causes paralysis on the opposite side of the body. This has been attributed to the decussation of the nerve tubes which may be seen in the *medulla oblongata*. This, however, could only account for paralysis of motion, whereas paralysis of sensation follows the same law. The investigations of Lockhart Clarke, however, have demonstrated that, whilst the motor columns of the cord only decussate in the medulla oblongata, decussation of the posterior columns takes place throughout the whole extent of the cord. (Plate XVI. fig. 1.) Many cases collected by Brown Séquard shew that while lesions above the medulla oblongata have a crossed action both as to motion and sensation, below that centre paralysis of sensation only is crossed, while that of motion is direct.‡

With the spinal cord, as with the brain lesions, such as chronic softenings have occasionally occurred to a considerable extent without paralysis;§ but it is probable, in all such instances, that the whole of the white, or of the conducting tubular matter, was not destroyed. In disease of the grey central substance, the power of combining or co-ordinating movements is lost (*locomotor ataxia*), sometimes combined with *progressive muscular atrophy*. Diseases of the membranes, on the other hand, induce pain, spasm, tetanus, &c.

The correctness of Marshall Hall's views as to reflex actions being independent of sensation, is conclusively demonstrated by those cases in which the cord was so injured as to produce perfect paralysis of the inferior extremities, so that on pricking them with a sharp-pointed instrument, or tickling the soles of the feet—the intelligence of the individual being perfect—the limbs are thrown into convulsions, without any pain or irritation being felt.* Nasse and others also have related examples, where, in consequence of spinal disease, women have gone through the stages of labour, and had healthy children, without the slightest suffering. The same result is now brought about by means of ether or chloroform, which suspends the cerebral functions, leaving the spinal and sympathetic ones unaffected.

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* Med. Gazette, vol. i. p. 755.

† Reports, Case 271.

‡ Lecture VII. in Lancet, pp. 272–3.

§ Case of Dessault, Abercrombie, 3d edit. p. 350.

Brown Séquard has discovered a remarkable result of dividing one half of the spinal cord, between the seventh dorsal and third lumbar vertebræ in the guinea pig, viz., that in from three to five weeks the animal becomes epileptic. Further, that the attacks of the disease may be excited by irritating or pinching a certain space of the face and neck below the ear of the side injured. This space is about 1½ inches long and 1 inch broad, and is anæsthetic. After a time, the hairs covering the part become crowded with *pediculi.* Epilepsy has also in the same manner occasionally followed section of the sciatic nerve.†

The existence of cerebral, spinal, and cerebro-spinal diseases must ever be most interesting to the physiologist, whilst the innumerable forms of spasm or convulsive disorders, all of which are reflex and essentially spinal in their character, present a wide field for study, in the prosecution of which the work of Dr Marshall Hall will be found of inestimable value. The cerebro-spinal system has also a therapeutics of its own. Certain remedies, such as tea, coffee, chloral, and opium, excite or diminish the cerebral functions; others, such as strychnine, hemlock, Calabar bean, and tobacco, excite or diminish the spinal functions; whilst a third class act both on the brain and spinal cord, such as cold, hydrocyanic acid, and alcohol. Some of these remedies are also antagonistic of the other. Thus we have proved experimentally that chloral will suspend the spasms and preserve life after fatal doses of strychnine and of the Calabar bean.

The elucidation of the intricate functions we have now discussed is mainly due to three distinguished physiologists, whose labours constitute three distinct epochs in the discovery of the functions of the nervous system. The first of these epochs is characterised by the establishment of contractility and sensibility as inherent properties of the muscular and nervous tissues. Such was the great discovery of Haller. The second is indicated by the demonstration of nerves of sensation and nerves of motion, and of mixed nerves in connection with their spinal roots. Such was the discovery of Charles Bell. The third epoch is marked by the separation of numerous combined actions from sensation, volition, and contractile movements, the demonstration that the spinal cord was their centre, and the fact that it was through a series of incident and excident nerves that they were accomplished. Such I hold to have been the discovery of Marshall Hall. Each of these great doctrines has given rise to an astonishing amount of discussion, the whole of which I have carefully considered, and unhesitatingly declare that, in my opinion, there is no doubt as to the great merits of the individuals named both as originators and demonstrators of the important doctrines referred to.

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* See Dr Elliot's case. Lancet, 1837–8, vol. ii. p. 77.

† Comptes Rendus de la Societé de Biologie, vol. ii, 1850, p. 205; and Archiv. de Phys. 1869. p. 211.

The Cerebro-Spinal Nerves.

There are generally enumerated, after Willis, nine cerebral pairs and thirty-one spinal pairs of nerves.

All the so-called cerebral nerves, with the exception of the first pair, which is in truth a ganglion, may be regarded as belonging to the cranial portion of the spinal cord.

1. The first pair of nerves, called the *olfactory*, serve to receive and convey the influences excited by odours on the Schneiderian membrane of the nose—to which it is distributed—direct to the brain, to produce the sensation of smell. They contain grey matter mixed with white tubular substance, and thus histologically resemble the ganglia. (See Sense of Smell.)

2. The second pair, or *optic* nerves, receive and convey to the brain the influences excited by light, so as to produce the sensation of sight. In the commissure, or chiasm, the nerves of the two sides undergo partial decussation, the effect of which, according to Mayo, is that the tubules from either optic ganglion are distributed to its own side of both eyes, and receive the impressions of objects on the opposite sides of the body. (See Sense of Sight.)

3. The third pair of nerves, or the *motor nerves of the eyeball*, are purely motor, and regulate all the movements of the eyeball, except those which depend on the external rectus and superior oblique muscles. When irritated within the cranium, spasm

of all the muscles to which they are distributed is occasioned, and dilatation of the pupil. When divided there are produced, 1st, External strabismus; 2d, Paralysis of the *levator palpebræ*, which causes the upper eyelid to remain closed over the eye, constituting *ptosis;* 3d, The eye cannot be moved upwards, downwards, or inwards; and 4th, The iris is so paralysed that the most powerful light, directed into the eye, is incapable of exciting the least contraction of the pupil.

4. The fourth pair of nerves, or *pathetic*, also called *trochlear*, are purely motor, and govern the movements of the *trochlearis*, or superior oblique muscle of the eye. Irritation of the nerve causes spasm of that muscle, and division of it, according to Szokalski, causes slight deviation of the eye upwards and outwards, producing double vision, in which the same object appears as two, the one placed above the other.

5. The fifth pair of nerves, called *trifacial* or *trigeminal* divide into three branches,—two of which are purely sensitive, and the third is senso-motory. The sensitive branches terminate in the face, and communicate sensibility to the skin, various organs of the head, and to the external parts of the organs of special sense. It is also the great excitor nerve of these parts. Its communications also with the ganglia of the sympathetic system render its integrity of the greatest importance to various excito-motory, excito-sensory, and excito-nutrient actions of the head and face. The non-ganglionic branch distributed to the muscles of the jaws is motor, and governs the movements of mastication. Irritation or slight disease of any branch of the fifth gives rise to great pain, or *neuralgia*, and to that severe form of it called *tic douloureux*. Division or destructive disease of it causes paralysis of sensibility in the face exactly limited to a line drawn through the middle of the forehead, nose, mouth, and chin. Pricking of a pin causes no pain; sternutatories placed in the nostril are not felt; and food on the affected side of the mouth gives no idea of its presence. On drinking from any vessel, it seems to be broken or cut away suddenly at the part where the paralysed lip is applied. In addition to these effects, which result from loss of sensibility connected with the ganglionic portion of the fifth, the motion of the jaw is impeded from paralysis of the motor branch. Mastication is interfered with in consequence of palsy of those muscles which subject the morsel to the action of the teeth,

and from the impaired grinding motion of the jaws. The individual can only chew on the sound side, the action of the masseter and temporal muscles of the affected side being more or less imperfect or lost. There is still command over the features, however, and no distortion of the countenance or loss of expression. The jaw is in some cases a little depressed, but this almost disappears when the individual smiles or laughs. This form of paralysis rarely exists alone, but is most commonly associated, as in hemiplegia, with palsy of the facial also, which we shall subsequently describe. (See seventh pair of nerves.) It may be more or less general, affecting the first, second, or third branches of the nerve, and in every case a knowledge of its anatomy and physiology will indicate the effects produced.

Magendie and Desmoulins were of opinion that all special sensibility was dependent on integrity of the fifth pair of nerves. Although this idea is incorrect, there can be no question that injury of this important nerve more or less interferes with, and ultimately destroys, smell, sight, hearing, and taste. This results from the loss of that common sensibility which appears indispensable to the secretion of mucus from the mucous membranes, so that they become dry and inflamed, inducing a condition incompatible with the proper performance of the functions of special sense.

6. The sixth pair of nerves, called *abducent*, are motor, and govern the motions of the external rectus muscle of the eyeball. When irritated, that muscle is convulsed, and when divided, compressed, or disorganised, it is paralysed, and the eye is turned outwards.

7. The seventh pair of nerves are composed of two parts, which are really separate nerves. The hard portion, or *facial nerve*, is motor, and governs the movements of all the muscles of the face. The soft portion, or *auditory nerve*, transmits the influences of sound through the internal ear to the brain, to produce the sensation of hearing. (See Sense of Hearing.) The motor portion, when irritated towards its terminal branches, sometimes occasions pain, which is attributed to its anastomosis with the sensitive filaments of the fifth pair. It always, however, causes convulsion or spasm. Section or destructive disease of the nerves within the cranium, or where it emerges from the stylo-mastoid foramen, causes general paralysis of the muscles of the face. The aspect of the face then differs accord-

ing as the muscles are in a state of repose or activity. In the former case, all expression is lost in the paralysed part ; the two sides of the face are not symmetrical, and when viewed by themselves, apparently belong to different individuals. The features generally are dragged toward the sound side ; the mouth is oblique, and its centre does not correspond to the axis of the body. The paralysed half of the face is a little more prominent than the sound one, which is wrinkled, contracted, and concealed behind the other, when viewed in profile. The paralysed side also appears broader than the sound one, while the eyelids are opened wide, and the eye appears more voluminous than its fellow. When, on the other hand, the individual speaks, laughs, cries, sneezes, or coughs, the deformity of the countenance is much increased, the mouth and features remaining perfectly motionless on the paralysed side, while on the other, they appear thrown into inordinate action. The muscles moving the jaws, however, which are supplied by the motor portion of the fifth, are still obedient to volition ; mastication is readily performed, and the patient can hold solid bodies between the teeth. The cheek on the affected side is flaccid, it swells at the moment of expiration, and especially when the patient wishes to blow or pronounce a word with emphasis. The lips are paralysed, and the saliva and food sometimes escape from the mouth on the palsied side. The pronunciation of certain letters, as *o*, *b*, and *p*, which require the intervention of the lips, is imperfect. Lastly, the patient cannot expectorate or direct the saliva to any given point at a distance from his mouth. Occasionally he can articulate with tolerable freedom, by supporting the paralysed cheek with his hand. *Lagophthalmia* is also frequently present, exposing the eye to constant irritation, and often producing ophthalmia. This form of palsy may be more or less general, dependent on the number of branches of the *portio dura* distributed to the face, which are affected.

Integrity of the facial, like that of the fifth nerve, is necessary to the proper performance of certain special senses, regulating as it does the movements of the nostrils, eyelids, and muscles of the internal ear. Great discussion has occurred as to how far the *chorda tympani*, which is a branch from it, is concerned in the sense of taste, a point in physiology not yet determined.*

8. The eighth pair of nerves are divided into three branches :

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* See Lussana and Vulpian Archives de Phys. 1869.

1st. The *glosso-pharyngeal*, distributed to the root of the tongue and pharynx, is a nerve of sensibility, administering to taste and touch in the former situation, while it is the great excitor in the act of deglutition in the latter. Irritation of it causes pain, and if injured before it gives off its pharyngeal branches, extensive muscular movements are produced in the throat and lower part of the face. This was shewn by John Reid to depend on reflex action, the pharyngeal branches of the vagus being the excident or motor nerves. Disease or destruction of the glosso-pharyngeal induces difficulty or complete paralysis of deglutition, from the loss of that power of receiving and transmitting impressions so essential for all reflex actions.

2d. The second branch is the *par vagum*, or *pneumo-gastric* nerve, which is distributed to numerous important parts, its branches having different functions. As a whole, it is a motor and sensitive nerve, and contains incident and excident filaments. The pharyngeal and inferior laryngeal branches are wholly motor ; its superior laryngeal branch is the sensitive nerve of the larynx, but is mixed with a few motor filaments which supply the crico-thyroid muscle ; the cardiac, pulmonary, œsophageal, and gastric branches are senso-motory. The results of experiments have shewn that irritation of the *pharyngeal branches* always produces contractions of the pharynx directly. Irritation of the *superior laryngeal* nerve causes contraction of the crico-thyroid muscle only, whilst that of the inferior laryngeal causes forcible contraction of the laryngeal muscles, as well as of the inferior constrictor of the pharynx. In a living animal the slightest touch on the mucous membrane of the glottis will cause its instant closure, if the superior laryngeal nerve be uninjured, but if that nerve be divided on both sides, the glottis may be irritated with impunity. Injury or complete section of the *recurrent nerves* causes also impairment or loss of voice. The *œsophageal branches* of the vagus, if irritated, produce contractions of the œsophagus, which extend throughout the whole tube to the cardia. Their section, or that of the vagus in the neck, causes palsy of the œsophagus, in which case the tube, during eating, becomes filled with the propulsive efforts of the pharynx, and the food even finds its way into the larynx and trachea. (Reid.)

Section and injury of the *cardiac branches* of the vagus do not materially influence the actions of the heart. Weber was the first to notice that strong stimulation of the vagus above these branches caused arrestment of the heart's contractions, with relaxation of its walls. This Pflüger attributed to an inhibitory action,—an idea opposed by Moleschott and others. According to Von Bezold, however, the movements of the heart appear to be influenced by three systems of nerves. One of these, seated in the heart itself, influences more especially its rhythmical action. A second, formed by the pneumo-gastrics, checks its action. The third, consisting of the sympathetic trunks in the neck and cardiac plexus, which are connected with the spinal cord, renders the organ answerable to the emotions of the mind. They all freely anastomose with one another, and produce compound effects, according to the amount and degree of the nervous influences affecting one or the other. Cyon and Ludwig describe a *depressor* nerve, arising in two roots—one from the vagus, and another from the superior laryngæal. Its division causes no marked result, nor does irritation of its lower cut surface. But if the upper cut surface be stimulated, there is a diminution in the force and frequency of the cardiac beats, while the aorta and visceral arteries are dilated; so that it operates through the vaso-motor system of nerves.

Section of one pneumo-gastric above the *pulmonary branches* produces no effect on the action of the lungs. But when both nerves are divided, severe dyspnœa and asthma are occasioned. The lungs become congested and œdematous, and the bronchi filled with serous fluid. Animals never survive this operation beyond three days, if the cut ends of the nerves be separated; but if brought in contact, they will live ten or twelve days (Reid).

Section of the *gastric branches* of the vagus cause, in the first instance, vomiting and loathing of food, and retard without putting an end to the digestive process. It weakens the contractions of the muscular coat of the stomach, which, however, are supplied from the sympathetic, but does not interfere with the secretion of the gastric juice.

The vagus also forms most important connections with the sympathetic system of nerves; and, like the fifth, is instrumental to numerous excito-motory, excito-secretory, and excito-nutrient functions of the neck, chest, and abdomen.

3d. The third branch of the eighth pair, or *spinal accessory*, is a motor nerve, the external division supplying the external muscles of respiration—the sterno-mastoid and trapezius—and the internal division, adding motor filaments to the vagus. On dividing it within the cranium, Bischoff observed that it caused loss of voice, and Bernard maintains that although respiration and phonation seem anatomically confounded, they are physiologically independent. He believes the vagus acts in producing the muscular movements of the former of these functions, while the spinal accessory regulates those of the larynx and chest engaged in the latter function.

9. The ninth pair of nerves, or *hypo-glossal*, is the motor nerve of the tongue. Its irritation induces spasms in the muscles it supplies, while section paralyses them.

Spinal nerves.—There are thirty-one pairs of nerves which belong to the vertebral portion of the spinal cord, all of which are senso-motory,—the posterior ganglionic root being sensory, and the anterior motor. (See p. 309.) These, united, form a compound nerve, containing sensitive and motor filaments necessary for sensation and combined motions, including incident and excident filaments in connection with distinct portions or arcs of the spinal cords as centres of diastaltic movements. The use of the ganglia are not known. They do not act as centres of reflex movements, as division of the posterior roots between the cord and ganglion destroys all such movements.

THE SYMPATHETIC NERVES.

This system of nerves has also been called *ganglionic*, *organic*, and *tri-splanchnic*. It consists essentially of a number of ganglia containing numerous nerve cells, communicating by one series of connecting nerve-tubes with each other, and by another series with the cerebro-spinal nerves. The structure of a ganglion is well seen, Plate XVI. fig. 3, *a*. The ganglia are arranged, according to their situation, into cephalic, cervical, thoracic, and abdominal ; while the connecting filaments, forming plexuses, have received numerous names in different parts, such as carotid, cardiac, diaphragmatic, supra-renal, hepatic, splenic, superior and inferior mesenteric, &c., &c. The connection between the cerebro-spinal nerves, and those of the sympathetic system is indirect through ganglia, which break the conducting power of the nerves, or modify it,—probably both.

Senso-motory properties.—Under ordinary circumstances, no act of volition or of the mind can induce movements in parts supplied by the sympathetic ; but under peculiar circumstances, or under the influence of unusual stimuli, movements are induced. Thus the emotions and desires, shame or fear, influence the movement of the heart and the contractile power of the capillaries, which an effort of volition cannot do. Such results are only explicable by the connection of the sympathetic system with nerves coming direct from the brain. Direct irritation of the sympathetic ganglia will also cause movements in the non-voluntary muscular parts receiving filaments from them. In the same way, for the most part, the internal organs and surfaces supplied by these nerves are not endowed with ordinary sensibility, and the mind is unconscious of their action ; but occasionally very severe pain is produced from their being the seat of disease, as in certain agonising pains of the heart (*angina pectoris*), in the intestines (*colic*), in the stomach, liver, kidneys, &c., &c. Thus, although in health, the sympathetic system so diffuses the influences conducted, that they are not obedient to or excite mental acts, there is abundant proof that the cerebro-spinal filaments passing through the ganglia are constantly operating, although insensibly, in subjection to the cerebro-spinal centres. The ganglia, however, not only diffuse the influence of impressions coming from and sent to the cerebral and spinal centres, but they are nervous centres themselves, and especially centres of numerous reflex acts in non-voluntary muscles.

Excito-secretory and excito-nutrient properties.—In addition to this excito-motory function of the sympathetic system, there is another of great importance, denominated by Dr Campbell, of the United States, *excito-secretory.* We have previously seen, however, that secretion in glands is only a form of nutrition ; and the influence of this system would appear not only to be exerted on glands, but on blood vessels and nutrition generally. It is, therefore, also *excito-nutrient,* and carried on wholly independent of the cerebro-spinal system. Thus it has been shewn by Sir B. Brodie that division of the crural and sciatic nerves neither retarded nor impaired wounds and fractures of the inferior extremities ; while numerous experiments have proved that injury to the large sympathetic ganglia occasion the most destructive effects to the nutrition of the parts which receive nerves from them. The experiments of Brown Séquard and Harley on the supra-renal capsules, have shewn that it is difficult to preserve animals if the semilunar or solar ganglion be much injured in the operation ; but if this be avoided, animals can live without the supra-renal capsules for a length of time. Again, as illustrative of the general influence of the sympathetic system over nutrition, is the fact that certain fœtuses have been born with well-developed textures, without a brain or spinal cord, in the same manner that many of the lower animals are destitute of these organs.

As local examples of this excito-secretory and excito-nutrient function of the sympathetic system of nerves, may be cited,—1st, The effusion of tears from the lachrymal gland on the application of an irritant. In this case the incident nerve is the palpebral branch of the fifth, and the excident or secretory the lachrymal branches from the carotid plexus. 2d, The secretion of saliva on irritation of the gums, or exciting the mouth by food and mastication. Here the incident nerves are the buccal branches of the fifth, and the excident or secretory the parotid branches derived from the carotid plexus. 3d, Dentition in infants and children give numerous examples of excito-secretory and excito-nutrient actions. Thus, from tender gums, and irritation of the dental branches of the fifth, the eye may become lachrymose and congested ; the Schneiderian membrane congested, and its secretion increased ; while diarrhœa is one of the most common symptoms. In these cases the excident nerves are derived from the ciliary and Meckel's ganglia, distributed to the conjunctiva and Schneiderian membranes, and through the splanchnic, with the intestines. 4th, The process of lactation exhibits the remarkable influence of excitation applied to the sensitive surface of the nipple. This, when grasped and suction made upon it by the infant, not only occasions increased flow of milk, but causes that peculiar feeling of the rush which mothers describe, and which is apparently owing to congestion of the blood vessels. Keeping up the flow of milk by constant milking long after it is required for suckling, as is constantly done for domestic purposes among our cattle, is an excellent example of the power of exciting such secretions locally. 5th, The secretion of starch from the liver, and its ready transformation into sugar, is influenced by irritations of branches of the eighth pair in the lungs, and by direct injury of the pneumogastric nerves, through the sympathetic branches of the cœliac and solar plexuses going to the liver. 6th, The increased quantity of urine often secreted, as the result of certain nervous irritations, especially in hysterical and excitable women, and which are only explicable as a result of reflex actions propagated through the ganglionic plexuses to the kidneys. 7th, The occurrence of intestinal disorders must be attributed to similar causes, especially the diarrhœas which follow exposure to cold, and the remarkable feeling of sinking and prostration to the economy which accompanies or follows colic, tormina, and other lesions of the bowels. 8th, The dissections of Dr Robert Lee have shewn a great development of the ganglionic system of nerves in the pregnant uterus, which would seem to govern not only its own increased growth, but by its influence over the vessels to regulate the nutritive supply of blood so necessary to the development of the fœtus. 9th, The feeling of shock which follows an extensive or sudden injury, or a feeling of acute agony, seems to owe its general exhaustive effects to the influence of the ganglionic system. It was shewn by Wilson Phillip that the brain and spinal cord might be removed entire, if the operation were carefully performed, without inducing the sudden effects of shock. But that when any part of the body was violently contused, then the surface became pale and cold, the heart's action faltered, the pulse was small, and every symptom of depression was manifested.

All these, and various other actions, are intimately connected with the influences of the ganglionic system of nerves over the blood vessels, which we have next to notice.

Influence on animal heat.—Division of the sympathetic in the neck was observed to produce remarkable changes in the eye, especially redness of the conjunctive, contraction of the pupil, retraction of the eyeball within the eye, &c., by Parfour du Petit in 1727, by Dupuy in 1816, by Brachet in 1837, and by John Reid in 1838. In 1852 Bernard announced his discovery that, in addition to these phenomena, the operation caused great increase of animal heat on that side of the head on which the sympathetic had been divided; and Brown Séquard shewed that galvanisation of the sympathetic diminished the temperature, and produced contraction of the arteries.

The elevation of temperature commences immediately after the section of the sympathetic trunk, between the inferior and superior cervical ganglia, so that not unfrequently in a few minutes a difference in temperature amounting to 4° or 5° centigrade exists between the two sides of the head, and is readily appreciated by the hand. In rabbits these disappear in 15 or 18 days, but in dogs they continue six weeks or two months. After extirpation of the superior cervical ganglion the effects are more rapid, intense, and lasting. In a dog operated on by Bernard, they were still very intense a year and a half after removal of the superior cervical ganglion. If the animal remain in good condition, no œdematous or inflammatory action takes place. But should it fall sick or become exhausted, the nasal and ocular mucous membranes of the affected side become red and swollen, and discharge pus abundantly. These results, described by Dupuy, John Reid, and others, are not necessarily caused by section of the sympathetic, but by the debility of the animal. Bernard conclusively proved that this increase of temperature did not follow section of the sensory or motor nerves. Brown Séquard shewed that, when the cephalic end of the divided sympathetic nerve is irritated by a strong interrupted galvanic current, the phenomena caused by its section disappear. The pupil, from being contracted, becomes larger than on the sound side ; the eye, which was sunken, projects from the orbit ; the vascular turgescence of the parts disappears, and their temperature falls below the natural standard. When the galvanic current is stopped, the phenomena produced by the section reappear, and on its renewed application are again dispelled.

These remarkable effects are attributable to section of the sympathetic nerves, causing paralysis, relaxation, and congestion of the blood vessels, whilst irritation of the nerve induces their contraction, and a diminished flow of blood.

The vast importance of these facts in explaining the cause of numerous important diseases must be obvious. Thus fevers are ushered in by a feeling of cold or rigor, and followed by increase of heat, indicating irritation, and then paralysis of the sympathetic system of nerves. In inflammation there is added to mere vaso-motor phenomena some lesion of the excito-nutrient nerves, causing exudation from the blood vessels. In cholera there is prolongation of the cold or algide state, hence the pallor and blueness of the surface, and the congestion and enormous discharges from the gastric and mucous membranes. To these are superadded the excito-motory actions of cramp and spasms. Numerous other equally important examples might be added.

It follows that the functions of the sympathetic system of nerves are—1st, *Excito-motory*, thereby regulating the contractions of the non-voluntary muscular fibres; 2d, *Excito-secretory*, whereby the various secretions are governed; 3d, *Excito-nutrient* or *vaso-motor*, operating more especially on the blood vessels, and thereby regulating the circulation in the capillaries, and the amount of animal heat.

SPECIAL SENSES.

The nature of sensation has already been dwelt upon; and it has been shewn to depend essentially on the existence of mind, or the consciousness of impressions made on the sensitive nerves. Perfumes do not exist in flowers, heat in fire, nor sound in a musical instrument. It is the effect produced on our minds through the senses that call such sensations into existence. The impressions which result from the stimuli of odours, sapid bodies, contact of hard or irritating substances, of light and of sound, however, are different. For the reception of these, nerves with peculiar endowments are provided; and to them are added a special structure or organ adapted for the purposes of smell, taste, touch, vision, and hearing. It is possible, as previously noticed (p. 286), that there may be tubules possessing endowments for conveying influences from other impressions than those just referred to, but these are not yet known. Hitherto many distinct sensations have been considered as only varieties of one sense, such as with regard to touch, those of pressure, tickling, pain, cold, warmth, smoothness, roughness, hardness, softness, &c. So with the widely different kinds of smell, taste, sounds, and ocular images. In a case of partial paralysis under my care, it was distinctly proved that the individual was insensible to cold applications, while warm ones were immediately recognised; and there are individuals in like manner who can readily detect some smells, tastes, sounds, and colours, while they cannot distinguish others. Again, the sensations of hunger and thirst, of weariness and sickness, cannot be referred to any of the five recognised senses. These facts point to the existence of additional endowments in certain nerve tubules as distinct from each other as those which are capable of transmitting the influences produced by light or sound.

Smell.

The material cause of odours is the presence in the air of substances in an extremely fine state of division, or gaseous matters, often of a very subtle description. According to Professor Graham, "odorous substances are in general such as can be readily acted on by oxygen. For example, sulphuretted hydrogen, one of the most intense of odours, is rapidly decomposed in the air by the action of the oxygen of the atmosphere. In like manner the odorous hydro-carbons are all oxydisable—the ethers, alcohol, and the essential oils that make aromatic perfumes. The gases that make no smell are not acted on by oxygen at ordinary temperatures. The marsh gas, carburetted hydrogen, is a remarkable case in point. This gas has no smell. As a proof of the absence of the oxydisable property, Professor Graham has obtained a quantity of the gas from the deep mines where it had lain for geological ages, and has found it actually mixed up with free oxygen, which would not have been possible if there had been the smallest tendency for the two to combine. Again, hydrogen has no smell, if obtained in the proper circumstances. Now this gas, although combining with oxygen at a sufficiently high temperature, does not combine at any temperature endurable by human tissues. It is further determined that, unless a stream of air containing oxygen pass into the cavities of the nostrils along with the odoriferous effluvium, no smell is produced. Also, if a current of carbonic acid gas accompanies an odour, the effect is arrested. These facts go to prove that there is a chemical action at work in smell, and that this action consists in the combination of the oxygen of the air with the odorous substance."*

All animal effluvia are dense gases (except sulphuretted hydrogen), and are diffused slowly. In course of a little time they will mingle with the lighter gases, according to the law of diffusion, but inasmuch as they thereby become diluted, the odour will best be perceived somewhere near the ground. It is on this account that the pointer and bloodhound run with the nose to the ground. The effluvia from decaying matter will be smelt in the ground floor, scarcely perceived by the persons in the first floor, and perhaps not at all in the garrets. Hence, it is thought, the danger of lying on the ground in tropical swamps, while suspended on poles or from a tree in a hammock, a person may pass the night in safety. In Naples, where the soil is volcanic, and the air tainted with unpleasant smells, the better class of inhabitants live in the upper stories.

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* Bain on the Senses and the Intellect, p. 163.

To cause smell, all odorous substances must be transmitted in a current over the membrane on which the olfactory nerve is ramified. This, in animals who live in air, is accomplished by the respiratory movements ; and hence suspension of respiration prevents the perception of odour, or sense of smell, whilst repeated quick inspirations, as in the act of *sniffing*, renders it more intense and prolonged. On this account the sense of smell has been considered an appendage to the function of respiration, as that of taste is an appendage of the function of digestion. This view is supported by the fact that the mucous surface of the nostrils, like that of the respiratory apparatus, is covered with columnar ciliated epithelium. The acuteness of scent varies in different animals, and bears a certain relation to the size of the nostrils and turbinated bones, being greater where these are large and extended.

Histology of the organ of smell.—The olfactory bulb, according to Lockhart Clarke,* is a remarkable ganglion, composed of various layers of nuclei, multipolar cells, and nerve tubules, terminating in a ciliated epithelial surface in the centre, where there exists a cavity or ventricle. The nerves also sent through the cribiform plate of the ethmoid bone terminate in an epithelium of a sepia brown colour (Todd and Bowman), which covers the deep-seated portions of the turbinated bones, and the upper third of the septum of the nose. They consist of gelatinous nerve fibres, with nuclei embedded in them, and towards their external extremities give off lateral fine-branched filaments before connecting themselves with the epithelium. This consists of flat nucleated plates, figured by Eckar (Plate XVI. figs. 4 and 5), Clarke, and Schultze, containing finely-molecular matter, sometimes ending abruptly (Fig. 5), at others having cilia at their free surfaces (Schultze). It is necessary that the mucous surface covering the expansion of the olfactory nerves should be moderately moist ; for if it be too dry on the one hand, or too moist on the other, the sense is impaired or lost. The ducts of the mucous glands, therefore, pass freely between the epithelial plates, and diffuse mucous over the surface. (See

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* Zeitschrift f. Wissesaft. Zoologie, bd. xi. heft. 1.

Fig. 4. *d*, *e*.) The situation of the sensitive surface high up in the nostrils secures it from the direct contact of air, so as to prevent rapid evaporation and dryness; while the convolutions of the turbinated bones, over which the currents of air pass before reaching the seat of special sense, communicate heat to them, and thus prevent the action of cold. The peculiar structure described, induced Todd and Bowman to suppose that the olfactory bulbs received the influence of impressions in the same manner that a nervous centre or ganglionic plexus does,—that is, at once and at first hand,—so that the mind becomes cognisant of them without their being conducted by means of white substance to the brain. This idea, though ingeniously derived from the histological arrangement, is opposed to the fact that smell has the same connection with mind as all the other sensations.

Pathology.—The sense of smell may be exalted, perverted, or lost. It is apparently increased by education, of which the case of James Mitchell is an interesting example. This boy was born blind, deaf, and dumb, and chiefly depended on smell for keeping up a connection with the external world. He employed it on all occasions, like a domestic dog, in distinguishing persons and things. In some cases, smell is exceedingly acute for particular substances, so as to be intolerable and distracting to those who suffer from it. Certain flowers, or particular odours, have in this way caused fainting or other bodily disorder. In other cases the smell is perverted or diminished, and occasionally is lost, as when the Schneiderian membrane is inflamed. Good relates the case of a lady who never possessed the faculty of smelling, a defect supposed to depend on congenital absence of the olfactory nerve. Of this, examples, found after death, are recorded by Cerutti, Pressat, and others. In a similar observation by Bernard in a woman, it was asserted after her death, by those who knew her intimately, that she smelt perfectly well.*

In recent times it has been strongly maintained that certain smells, and the emanations that give rise to them, are the cause of wide-spread and dangerous epidemic diseases. The causes of these, in truth, are very obscure, and nothing therefore is easier than to attribute scarlatina, typhus and typhoid fevers, diphtheria, &c., to some smell inherent in the natural evacuations from plants and animals, or resulting from their putrefaction. The following considerations, therefore, may be valuable in a sanitary point of view.

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* Systeme Nerve ix. tom. ii. p. 232.

I. *Many places with strong odours have been proved never to produce disease.*—This has been shewn—1. In the perfumed plains near Cannes, Nice, &c., where flowers are largely cultivated to produce distilled fragrant essences. 2. Formerly at Montfaucon, in Paris, and at present in the Forest of Bondy, where the sewage of Paris is manufactured into *poudrette*, the smell was and is intense, and has often been complained of as a nuisance, but at no time could it be shewn to have originated disease. 3. The Thames, in 1858, in consequence of its disgusting putrid odours, was loudly complained of, but no disease was caused by it. 4. The Craigintinny meadows, near Edinburgh, have for 200 years been rendered fertile by causing the drainage of the city to flow over them. The odour is often very bad, but they occasion no unhealthiness. 5. The drains in Naples run down to the sea, having large slits in them opening into the streets, and the beautiful bay is rendered foul, close to the shore, with the drainage of the city. This, combined with the sulphuretted hydrogen given off from the volcanic soil, renders the atmosphere so unpleasant, that the rents of the dwellings, unlike what exists in other cities, augment as the apartments ascend in the stair. The *latrines* in the public hospitals also exhale the most fœtid ammoniacal gases. Notwithstanding, neither in the city nor the hospitals is fever, and especially typhoid fever, so common as in other cities of the same size. 6. Drs Livingstone and Kirk informed me that in Africa the smell of the mangrove swamps was often intolerable, but were never productive of disease.

II. *Atmospheric air, productive of the most dangerous epidemics, may be quite inodorous.*—This has been proved in various parts of the world, as in the marshes of Essex and Lincolnshire, the low grounds of Holland, the Campagna of Rome, the Delta of the Ganges, the swamps of Louisiana, the Guinea coast, Jamaica, and many other places. It has never been known that those who catch intermittent, remittent, or continued fevers, on visiting such localities, have connected the morbific causes with peculiar smells. It follows that—

III. *There is no necessary connection between smells and deleterious gases.*—Some of these have smells, such as sulphuretted hydrogen, whilst others are inodorous, such as carbonic acid gas. Now, it is to be observed, that what makes these and other gases injurious, is their being so concentrated as to exclude atmospheric air, or their being pent up in confined places, from which they cannot escape. Hence why workmen going down into pits expire, for the same reason that dogs do in the *Grotto del Cano*. It has been asserted, however, that smells, though not injurious in themselves, give indications of danger. At a discussion on this subject, which took place in the Physiological Section of the British Association in September 1864, one chemist maintained that, during putrefaction, the smell was given off first, and the noxious vapour afterwards; whilst another declared that the smell was given off last, and was the proof that all danger had ceased. The first likened smell to the tail of the lion, which, when seen, gave evidence that the claws and teeth were not far off; while the second, continuing the simile, declared that a sight of the tail was the best evidence that danger was departing. I do not believe that smells, as smells, are injurious to health, nor are they a nuisance to those who live among them, as the sense is most readily paralysed; yet, one of the great difficulties in making the sewerage of towns useful in agriculture, has arisen from exaggerated notions as to the danger of smells, and the necessity of deodorisation.

Taste.

This sense is dependent on the fifth and glossopharyngeal nerves,—the former distributed to the two anterior thirds, and the latter to the posterior third of the tongue. The experiments of Stich and Kllaatsch* shew that the sense of taste exists over the whole surface of the posterior third of the dorsum of the tongue, on the under surface of the tip, and in a band or line about one quarter of an inch broad, running along its edge. The sense is also well defined in the posterior parts of the hard palate, and in that portion of the soft palate which is near the bone. It is, further, present in the anterior pillars of the fauces. The middle and anterior part of the dorsum, the gums, posterior pillars of the fauces, and the inner surface of the lips, possess no sense of taste.

Histology of the organ of taste.—The tongue is covered over with minute papillæ, described by Todd and Bowman, which, when magnified, present four principal forms, viz.,—1st, Simple papillæ, which are scattered over the general surface of the tongue. They are buried in the continuous sheet of the epithelium, and present the general characters of the cutaneous papillæ; 2d, Conical or filiform papillæ. These project from the surface, and are furnished with long, pointed processes, some of which approach hairs in their stiffness and structure (Plate IX. fig. 8, *a*, *b*, *c*); 3d, Fungiform papillæ are scattered singly over the tongue, chiefly upon its sides and tip. They vary in number, from 160 to 290. (Szabadföldy.) They project considerably from the surface, are usually narrower at their basis than at their surface, and exhibit numerous simple papillæ on their surface. (Plate IX. fig. 8, *p*.) They contain a complex capillary plexus (Fig. 9 and Plate XI. fig. 14), among which lie the terminal loops of the nerves; and 4th, Circumvallate or calciform papillæ. These are 8 or 10 in number, and are situated in a V-shaped line at the base of the tongue. Each consists of a central flattened circular projection of the mucous membrane, surrounded by a ring of similar elevation, from which it is separated by a depression or fossa. The surface of both centre and surrounding ring is smooth, and covered by scaly epithelium, in which are embedded a multitude of simple papillæ. A vertical section exhibits the structure represented Plate IX. fig. 7. It is supposed that the two former are more especially concerned in the sense of touch, with which the tongue is also highly endowed; whilst the two latter, but particularly the last, constitute more especially the apparatus of taste.

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* Archv. f. Path. Anat., bd. xi 1858, p. 225, and bd. xviii. p. 80.

According to Todd and Bowman, the filiform papillæ, from their isolation and partial mobility upon one another, must render the delicate touch with which they are endowed more available in directing the muscular actions of the tongue. Sapid bodies pressed against the fungiform and circumvallate papillæ give rise to impressions which, when transmitted to the brain, occasion the peculiar sensation of taste. The sense is more acute in some persons than in others; may be intensified by education, as is remarkably well observed in wine tasters; and is diminished or lost in febrile or other disorders which alter the condition of the mucous surface of the tongue and mouth. It is intimately connected with, and modified by, the sense of smell, so that closing the nostrils diminishes and often destroys that of taste. The pungent sensations caused by mustard, pepper, &c., are owing to the excitation of touch, and should be separated from those of taste. Like that of smell, the sensation of taste is soon paralysed, though not so readily. On repeated sipping of a high-flavoured wine, it ceases to be tasted, until the function be removed by eating a little cheese or other flavoured substance.

There can be no doubt that the tongue furnishes us with a proof that the same nerve which administers to ordinary sensibility, or the sense of touch, also communicates special sensibility, or that of taste. What, however, is more difficult to explain, is, that while the one sense may be paralysed, the other may remain perfect. Several cases demonstrate this. Thus, a lady, observed by Mr Noble, had half the tongue insensible to ordinary physical agents. A knife placed in boiling water, and laid horizontally on the tongue, was only felt on the right side. The left side, when wounded by a lancet, caused no feeling of pain. The patient could distinguish on both sides with equal delicacy bitter, sweet, and saline substances. An ingenious experiment gave at once the double demonstration of loss of tactile sensibility and preservation of special sensibility. The tongue having been thrust out of the mouth, a piece of salt and a piece of sugar were allowed to fall separately on the right and left side. The shock and the contact were felt on the right side only, but when the substances began to melt, the taste was felt at once on both sides.* Vogt, Bernard, and others, have described similar facts, which support the conclusion that some other nerve must be connected with the special sense—supposed to be the *Chorda Tympani.* (See p. 319.)

Touch.

This sense is dependent on the nerves of common sensibility distributed to all parts of the surface. But here also we observe that a distinct structure is necessary for the manifestation of the peculiar property.

Histology of the organ of touch.—This consists in the papillæ of the true skin, which are variously modified in different parts of the body, in proportion to the acuteness of the sense. In the papillæ of the fingers and a few other places, minute indurated bodies of condensed fibrous tissue were discovered by

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* Gaz. Med., 1835, p. 103.

Wagner, called *touch bodies* (Plate XVI. fig. 10), which have been supposed capable of rendering this sense more acute. They are in immediate relation to a nerve ; and the well-known effects of pressing such nerve against a hard body, as in the case of a corn, may well be supposed capable of exalting the sensibility. It was supposed by Wagner that the papillæ which contain these "*axile bodies*," were different as regards vascularity from others which only contain capillary loops, such as those on the lips (Plate XI. fig. 10). But no such distinction between nerve papillæ and vascular papillæ in truth exist, the two textural elements mingling together in varied proportions. The Pacinian bodies are also composed of concentric circles of fibrous tissue forming an indurated body, in the centre of which a nerve terminates (Plate XVI. figs. 8 and 9). They are most common in the mesentery, especially of the cat, and Krause supposes they are connected with the mechanism and arrangement of the viscera required by that animal in the act of springing.* Though touch may be intensified, it cannot be said to be dependent on these bodies.

Weber and Valentin have made numerous experiments with a view of determining the amount of tactile sensibility in the skin at different places. These consisted in touching the skin, while the eyes were closed, with the points of a pair of compasses sheathed with cork, and in ascertaining how close the points of the compasses might be brought to each other and still be felt as two bodies. This point was termed by Dr Graves, "the limit of confusion." The results were, that the extremity of the third finger and the point of the tongue are the parts most sensitive, as in these places the difference of half a line could be distinguished. Next in sensitiveness to these is the mucous surface of the lips, where the two points of the compasses can be perceived when separated to the distance of about a line and a half. On the dorsum of the tongue they require to be separated two lines. The parts in which the sense of touch is least acute are the neck, the middle of the back, the middle of the arm, and the middle of the thigh, where the points of the compasses must be separated to the distance of thirty lines in order to be distinguished. Weber and Valentin have each given elaborate tables shewing these parts with others exhibiting the intermediate amount of tactile sensibility over the whole surface. Generally speaking, the trunk is more sensitive in the medium line, both before and behind, than at the sides. Some persons distinguish the points of the compasses at one-half or one-third the distance than others can. Czermak, also, has pointed out that certain individuals can recognise the points more readily if they are applied one after the other rather than applied together, although more closely approximated. When the skin is stretched, the delicacy of touch is diminished.

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* Zeit. f. Rat. Med., bd. xvii. p. 278.

We have already referred to the variety of feelings which may be excited by the sense of touch (p. 327), such as pressure or resistance, tickling, pain, cold, warmth, smoothness, roughness, hardness, softness, &c., and pointed to the probability that this may depend upon different tubules possessing different properties. Weber* made many experiments with regard to temperature. In three cases where the skin was destroyed by a burn, heat and cold could not be distinguished over the denuded surface. According to Northnagel,† slight differences in temperature are most easily recognised between 80° and 91° Fahr. The eyelids, cheeks, and temples, can distinguish variations amounting to not more than from 0.4° to 0.2° C. The hand and finger are about equally sensitive, but are less so than the forearm, and this again is exceeded by the upper arm, which can distinguish a difference of 0.2° C., and the same holds good of the foot, leg, and thigh. Increase of cold or heat beyond certain limits causes pain, and not a sense of temperature, and this pain is much the same whether caused by one or the other, as is often experienced in toothache. It has also been ascertained that below the skin the trunks of the nerves cannot recognise heat and cold, any more than the optic nerve, after leaving the retina, can be stimulated by light.

The power we possess of referring sensations to different parts of the surface is very much the result of education, and is obtained during infancy and childhood. Anything that intercepts the ordinary course of events, does not at once intercept our power of mentally associating the sense of touch with various organs. Thus pain in the stump of an amputated limb is still referred to the toes, and (why) if we cross our fingers, and touch rapidly in succession a round object with both, we feel apparently two bodies instead of one.

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* Müller's Archiv. 1849, Heft. iv. s. 273-283.

† Deutsch Archiv. f. Klin. Med., Bd. ii. p. 284.

Touch, like the other senses, is capable of being greatly improved, and intensified by practice, of which the well-known power of distinguishing objects and of reading by raised letters possessed by the blind, is an example. Professor Saunderson of Cambridge, who lost his sight when two years old, could distinguish by this sense genuine medals from imitation ones. Other blind men have, by their exquisite touch, been enabled to become sculptors, conchologists, botanists, &c.

Sight or Vision.

This sense is dependent on the optic nerve, and a very complex apparatus, consisting, in man,—1st, Of external protective parts ; 2d, Of a set of muscles destined to move the organ of vision in various directions ; 3d, Of the expansion of the nerves, and the addition of a ganglionic structure, whereby the rays of light are received, and the influence of the impressions they excite conveyed to the brain ; and 4th, Of an optical apparatus, consisting of transparent media, which refract the rays of light upon the retina. The eyeball itself consists of an external fibrous coat, a middle or vascular coat, an internal or nervous coat, and of contents composed of refractive media, a minute description of which is purely anatomical. All that need be referred to here is the special functions and histological structure of the individual parts of the eye, together with a consideration of the whole organ in relation to vision. For a clear appreciation of this subject, a knowledge of the physical laws connected with light is essential. (See p. 134.)

1. *The external protective parts*, composed of the eyebrows, the eyelids, and eyelashes, serve to shade the eye from excess of light ; to diffuse over the cornea the sebaceous matter and lacrymal fluid, whereby the surface is kept ductile and moist ; and lastly, to prevent the access of dust floating in the atmosphere. These different actions are for the most part involuntary, and carried on partly by the cerebro-spinal, and partly by the ganglionic system of nerves performing excito-motory, excito-secretory, and excito-nutrient functions. The watery fluid secreted by the lachrymal gland, and which is diffused over the anterior surface of the eye by the motion of the lids, keeping it moist and translucent, is conducted by two openings in the inner corner of the eye through the lachrymal duct into the nose, from whence it is discharged.

2. *The eye-ball* has a remarkable amount of mobility, in consequence of six muscles, four straight and two oblique, which act upon it in various ways. They are supplied by the third, fourth, and sixth pairs of motor nerves, and by a sensitive branch of the fifth pair. The object of so many nerves being distributed to them seems to be the correction or prevention of the simultaneous action which would take place in the two eyes if all their muscles were supplied by branches of the same nerve. Thus, in turning the eyes outwards, the third nerve acts in the one eye, and the sixth in the other. If the same nerves were stimulated in both eyes, they would be both turned either outwards or inwards. The action of these muscles, and its amount, can be well studied by means of the opthalmotrope of Reute (Plate XXI. fig. 23). (See Practical Physiology.)

3. *The retina.*—The optic nerve, on entering the eyeball, is a little compressed, but on reaching the internal surface, divides into minute branches which inosculate together to form a membrane. (See Plate XVI. fig. 6, *k*.) On the inside of this membrane is placed a layer of ganglionic cells (Fig. 6, *h*) embedded in molecular matter, which send off processes, chiefly outwards. These two layers contain a vascular plexus of capillaries derived from the *arteria centralis retinæ.* Immediately external to the ganglionic layer is a fine molecular layer—the vesicular layer of Bowman (Fig. 6, *g*), and outside this is a granular layer (Fig. 6, *d*), succeeded by another molecular layer—the *membrana fenestrata* of Krause (Fig. 6, *f*). Outside this is a second granular layer which sometimes presents a striated appearance (Fig. 6, *c*); and lastly, most external and close to the choroid membrane, is the bacillary layer, or membrane of Jacob, composed of rods and cones (Figs. 6, *a*, *b*), standing vertical to the retina, and composed of a structureless transparent substance resembling glass in appearance. The rods, which are external, and cones, are each composed of an outer and of an inner segment, which are separated from one another by a bright transverse line (Fig. 6, B, *b*, *c*, and C, *a*). The former have their thickest portion or shaft directed outwards, whilst with the latter it is the reverse, their broad bases resting on a thin membrane, called the external limitary membrane. According to Kölliker, the cones contain a nucleus, and are therefore elongated cells. These different layers are connected together by continuous filaments, running from the rods to the internal limitary membrane which is in

immediate contact with the vitreous humour. (Fig. 6, A, *v*.) These are the fibres of Müller. (See Fig. 6, *B* and *C*.) The whole retina is transparent, and the rays of light pass completely through it back to the choroid membrane, and are reflected by the rods of Jacob's membrane, forwards to the sensitive branches of the optic nerve, which convey the influence of the impressions so excited to the brain, to produce the sense of vision. This appears to be demonstrated by two facts: 1st, That at the point where the optic nerve enters there are only nerve tubules, and none of the ganglionic layers or rods, and this point is insensible to light. 2d, That in the foramen of Sœmmering in the axis of vision, the branches of the optic nerve and internal layers are absent, but the layer of rods and cones exist, and here sensibility to light is most perfect. The bacillary membrane would appear, therefore, to be the essential portion of the retina.

For the method by which the retina may be examined in the living subject, by means of the opthalmoscope, see Practical Physiology.

4. *The optical apparatus* consists of four lenses of different structures, densities, and curves, filling up the substance of the ball, and forming, with the strong external case or sclerotica, and the choroid, a perfectly achromatic camera obscura.

Cornea.—The most anterior of these lenses is the cornea, composed of condensed epidermis resembling horn; and hence its name. A vertical section through this structure exhibits (see Plate XVI. fig. 12), 1st, An external layer of nucleated epithelial cells forming the conjunctiva (Fig. 13 *a*) ; 2d, A clear structureless firm membrane, the *anterior elastic lamina* (Fig. 12, *b*) ; 3d, A laminated structure, the edges of which resemble fibres, with fusiform spaces or lacunæ communicating with each other, and attached to the anterior elastic lamina by crossed fibres (Fig. 12, *c*) ; 4th, Another structureless firm transparent membrane, the *posterior elastic lamina* (Fig. 12, *d*) ; and lastly, and most internally, a delicate layer, having a single layer of cells embedded in it—the membrane of Descimet. The cornea is furnished with a vascular zone of capillary vessels round its external margin, the larger central portion being non-vascular. Bundles of fine nerve tubules also proceed from the circumference, and form a wide-spread plexus through its substance.

Aqueous humour.—The second lens, proceeding backwards, is composed of a watery fluid, or aqueous humour, principally accumulated between the cornea and the iris. It contains in solution a minute quantity of chloride of sodium and extractive matter, but no structural element.

Crystalline lens.—The third lens is the crystalline—one of the most remarkable bodies in nature. It is of a bi-convex form, the posterior convexity being the greater, and is enclosed by a structureless capsule, lined by a delicate epithelium, the anterior wall being four times thicker than the posterior. The substance is composed of concentric laminæ, like those of an onion, united by serrated or notched surfaces, and increasing in density from the circumference to the centre. The external layer consists of transparent nucleated cells, which, after death, soon become loaded with water. (Plate XVI. fig. 7, *a.*) A thin section of the lens causes the edges of the laminæ to appear as notched fibres, the serrated margins varying in depth in different animals. (Fig. 7, *b*, *c*, *d.*) The edges of the laminæ or planes, as was described by Sir David Brewster, terminate in a stellate or triangular notch, anteriorly and posteriorly, the former having an intermediate position to the latter.

The vitreous humour.—The fourth lens, or vitreous humour, is of gelatinous consistence, fills up the large proportion of the ball, and appears to be a watery fluid inclosed within fibrous meshes of the greatest tenuity and fineness. After long steeping in chromic acid, Hannover shewed that in a vertical section a number of rays proceed from the centre to the circumference, resembling an orange laid open. In the fresh eye nothing is perceptible by a structureless gelatinous, or, as some call it, mucous substance.

These horny, watery, glassy, and gelatinous lenses, united, fulfil all the conditions optically required to produce achromatism so perfectly as to set the optician's art at defiance.

The choroid.—The eyeball is lined by a black opaque membrane, the choroid, to absorb unnecessary rays of light, placed immediately behind the vitreous humour. Posteriorly it consists of hexagonal pigment cells (Plate III. fig. 27, *c*), which become fusiform and branched anteriorly. Immediately behind the pigment cells is a rich plexus of capillary vessels presenting a peculiar and characteristic stellar arrangement (*Tunica Ruyschiana*). In connection with this membrane is the tapetum, in certain mammalia, a fine fibrous structure which strongly refracts light; the pecten in birds and the choroid gland in fishes. This membrane must be important in rendering vision distinct, as in Albino's, where it is deficient, a strong light causes confusion of sight. Draper supposes that the choroid absorbs the heat or calorific ray of light, and has its temperature raised in proportion to the intensity of the colour. It is in this local disturbance of temperature, he thinks, the act of vision commences.

The Iris possesses two sets of non-voluntary contractile fibres, composed of fusiform cells, with staff-shaped nuclei. The circular are internal, and immediately surround the perforation in its centre, or the *pupil.* The radiating fibres are external. The action of the former contracts, and of the latter dilates, the pupil. The contraction of the annular fibres is under the control of the third pair of nerves, while that of the radiating fibres is formed by the cervical portion of the sympathetic (Budge and Waller). The movements of the pupil must be regarded in their nature as reflex, the incident nerves being the optic, the excident the third pair, having the opthalmic ganglion as their centre. Contraction of the pupil may also be induced by squinting inwards, by strong accommodation of the eyes for near objects, and by certain poisons, as opium, tobacco, and the Calabar bean. The direct action of light produces the same effect as was long ago shewn by Mr Walker, of Manchester, in persons affected by double cataract. Brown Séquard has further proved that light and an increase of 50° or 60° temperature Fahrenheit causes contraction in the pupil, when the posterior part of the eye has been cut off. It may be also seen in eyeballs cut out from a living animal, proving that such motion is not only reflex, but may result from the direct action of light. Dilatation of the pupil is caused by accommodation of the eye to distant objects, and by belladonna and its alkaloid atropine.

The action of the pupil is most important in securing distinct vision, as the amount of light entering the eyeball is thereby regulated, superfluous rays excluded, and divergent ones cut off. Paralysis of the iris by belladonna causes dimness of sight, and optically, as is well known, too much or too little light interferes with the production of a clear image.

In regarding the entire eye as an organ of vision, there are various points which demand consideration. Among these are—

1. *The accommodation of the eye.*—The means by which the

apparatus is so readily accommodated to various distances. On this subject numerous theories have been advanced, all of which answer the purpose, if the truth of certain data be granted. It has been supposed that the curvature of the cornea is changed (Ramsden, Home); but this has not been demonstrated. It has been thought that the lens is drawn forward by a contractile non-voluntary muscle,—the ciliary muscle (Crampton, Bowman),—or is pushed forwards from behind by the turgidity of the ciliary processes (Wallace, Alison). Some have thought that the contractions of the iris have much to do with the focal adaptation of the eye (Knox, Brewster); and others, that it is owing to the pressure on the eyeball of the external muscles which move it (Arlt). The question is now completely answered. Cramer[*] pointed out that when the light, say of a candle, is placed at a certain angle before the eye, three images are visible. The first, seen upright, reflected from the cornea, the second also upright, reflected from the anterior surface, and the third inverted, reflected from the posterior surface of the lens. On accommodating the eye to a distant object, a considerable space exists between the first and second image (Plate XXI. fig. 24), which may be seen to be diminished when the eye is accommodated to near objects, by the advance of the second image towards the first. (Plate XXI. fig. 25.) It was clear, therefore, that the change was owing to an increased curvative in the anterior portion of the lens. Helmholtz also pointed out that the third image also underwent a very slight diminution in size, and that the posterior surface of the lens undergoes a little increase in convexity. The latter distinguished physiologist has constructed an instrument, *the Opthalmometer* (Plate XXI. fig. 24), which enables us to measure, with mathematical exactitude, the magnitude of the reflected images, their amount of deflection, and the extent of the increased convexity of the lens.[†] The cause of accommodation is, therefore, fully demonstrated. (See Practical Physiology.) The increased convexity of the lens cannot be caused by the contractility of the iris, as in the case of Graefe,[‡] where that membrane was wholly removed by operation, the power of accommodation remained; it follows, therefore, that the change must be caused by the pressure occasioned by contraction of the ciliary muscle.

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[*] Het Accommodatie, Vermogen, Physiologisch Tœgelich. Haarlem, 1853.

[†] Physiologische Optik, 1858.

[‡] Archiv. f. Opthalmologie, B. vii.

2. The natural power of adaptation is interfered with in *myopia*, or short-sightedness; in *presbyopia*, or long-sightedness; and in *amblyopia*, or a peculiar dimness of vision. The first is owing to too great curvature of the lenses, and is corrected by concave glasses in spectacles; the second is produced by too little curvature of the lenses, and is corrected by convex glasses in spectacles,—this condition has been called by Donders *Hypermetropia;* the third is owing to altered shape or oblique position of the lens, and is corrected by the use of cylindrical glass lenses.

3. *Colour-blindness.*—Another perversion of vision consists of what is called colour-blindness, or Daltonism. Some persons cannot distinguish colours at all, everything appearing shadowed or light, like an engraving. Others cannot see brown, gray, or neutral tints; whilst a third class confound red, blue, and yellow with green, purple, orange, and brown. Red, blue, and yellow are never confounded with each other; but red and green are most commonly so,—a matter of great importance to railway travellers, as at night the red light is the signal of danger. This condition may be dependent on some fault in the nerves of vision, possibly in the retina, and more especially in the refractive rods; or it may be owing to some change in the refractive media or lenses. But the theory is not yet determined.

4. *Position of objects.*—All objects refracted on the retina are inverted, and yet we see them in their natural position. To explain this fact, it has been supposed that during infancy this sense, with all the others, undergoes a slow education, and that one, so corrects the aberrations of the others, that gradually we learn to recognise things as we do (Müller, Volkman). The same explanation applies to a perception of the shape, size, and distance of an object. The case of Cheselden, who operated on a young man successfully who had been born blind, in consequence of congenital cataract, contains many facts in favour of this view. On the other hand, it has been urged that there is no reason why the mind should not perceive correctly, as well from an inverted as from an erect image.

5. *One object seen from two images.*—The circumstance of our seeing one object, although we receive two images in the two eyes, is explained by the regular action of the muscles of the eyeball. When this is deranged, as in squinting, or from the

use of narcotics, we see double. Hence impressions are made on the corresponding part of the retinæ in such a way that, if both eyes were united, the two portions of the membrane would each receive half the impression. The peculiar decussation of the optic nerves seems to connect exactly these two portions so that one sensation is occasioned (Mayo). Sometimes only half or a part of an object is seen ; a circumstance attributed to paralysis of a portion of the retina, or to some disorder of the brain connected with the terminations in that organ of the optic nerves. Mr Bowman considers that the crossing of the fibres acts as a commissure between the vesicular laminæ of the retinæ, in the same manner as the commissures act between corresponding portions of the gray matter of the cerebral hemispheres, so that, although organs are double, unity of function is the result. Here, again, it has been urged that the mental interpretation of the sensory impression is not to be accounted for by any structural arrangements of the sensorial apparatus.

6. *Entrance of optic nerve insensible.*—The retina, at the point where the optic nerve enters it, is insensible. This is shewn by the experiment of Marriotte. Shut the right eye, stretch out the arms, and place the thumbs together. Then, on moving the right thumb outwards, while we continue to look steadily at the left thumb, we shall observe that the former disappears when it comes opposite the entrance of the optic nerve, and reappears again when it has passed across it. The foramen of Sömmerring, in the direct axis of the eye, perfectly transmits the rays of light. This aperture, however, is not deficient in Jacob's membrane—a circumstance which points out the great importance of that structure as a sensitive medium.

7. *Impressions remain a certain time.*—An impression made on the retina remains a certain time. This is proved by looking at a dazzling light or bright colour, and observing that, on turning away the head suddenly, it continues for a longer or shorter period. It is also seen by whirling a stick lighted at the end, which appears as a ring, the impression being continuous from the time the light has left one point till it returns to it. An ingenious toy, called the " wheel of life," illustrates the same fact.

8. *Ocular spectra.*—Some persons are subject to ocular spectra, which are of various kinds. Fatigue of the organ causes specks or moving filaments to appear, and a blow upon it, or pressure

at night, induces a flash of light. Remarkable objects, inanimate or living, may be seen under circumstances preventing the possibility of their existence, which, notwithstanding, have all the aspect of reality. They always depend on a state of nervous exhaustion, from ill health, mental depression, or the use of certain drugs, as alcohol, opium, or other narcotic substances. The capability of determining from reasoning whether such spectra are real or unreal, is a strong test of the existing soundness of mind of the individual. Various causes may induce a deception of the sense, which may be divided into sensual and mental. If the former, walking towards the object, or attempting to touch it, will correct the deception. Another test exists in turning one's back to the object ; if a reality, it is of course lost; if it exist in the mind's eye, it is still seen. Sir D. Brewster pointed out that mental spectra follow the rotation of the eyeball. It would be well to employ the word *illusion* to ocular spectra dependent on disorder of the sense, and *delusion* as characteristic of perversion of the judgment, or of insanity.

Hearing.

It is necessary for hearing that certain oscillations in the air, water, or solid bodies, should reach the expanded filaments of the auditory nerve, and that the influence of impressions so produced should be conveyed to the brain. This is accomplished through the medium of a very complicated organ or acoustic apparatus, the ear, for a description of which we must refer to works on anatomy. The most essential part of the organ is the vestibule, that exists in every class of animals in which an auditory apparatus is to be detected. There also the principal expansion of the auditory nerve takes place, and there it is brought into connection with the vibrations of sound from the exterior. In man, such is the complication of parts superadded to the vestibule or central ear,—viz., the cochlea and semicircular canals,—that the whole is denominated the *labyrinth.* It consists of chambers and canals hollowed out in the solid part of the temporal bone, containing a fluid, in which various branches of the auditory nerve are ramified, and so arranged that the slightest vibration communicated to the fluid must affect the nerve.

Histology of the organ of hearing.—Under this head we shall confine ourselves to what is known with regard to the distribution and termination of the auditory nerve in the labyrinth.

The vestibule.—The vestibular branch of the auditory nerve sends separate branches to the utriculus, sacculus, and ampullated enlargements of the membranous labyrinth. This is surrounded by lymph externally (*perilymph*), and contains lymph internally (*endolymph*), and may thus be said to be suspended in fluid. It may easily be understood, therefore, how the slightest vibrations communicated to the internal ear, influence the membranous labyrinth, and immediately affect the nerves. Within the sacculus and utriculus is a mass of earthy matter (carbonate of lime), sometimes hard like a stone (*Otolith*), at others, soft like powder (*Otoconia*), with which the nerves are directly connected. Müller mentions that sonorous undulations in water are not felt by the hand itself immersed in the water, but are perceived distinctly through the medium of a rod or hard body held in the hand. It has been concluded, therefore, that the function of these mineral masses is to re-inforce the sonorous vibrations, and communicate to the nerves vibratory impulses of greater intensity than the perilymph alone could impart.

The cochlea.—The cochlear branch of the auditory nerve terminates, like the optic nerve, in a remarkable ganglionic structure, which is spread over the internal portion of the membranous zone of the *lamina spiralis.* On looking down upon the vestibular surface, we see the view represented (Plate XVI. fig. 12) by Ecker. Superiorly, is a thick layer of epithelial cells (Fig. 12, 1), the *membrane of Corti,* below which is the *ligamentum membranæ tectoriæ* (*tectorium*, a cover). (Fig. 12, 2.) Underneath this is a membrane, the *habenula sulcata* (*habenula*, a small strip of flesh) (Fig. 12, 3), with a denticulate zone to the right (*b*), and external to this, another mass of nucleated cells (*d*), which fill up the space between the membrane of Corti above, and the *membrana basilaris* (*m*), below. Between these membranes lie the organs of Corti (*l*, *g*, *k*, *i*), consisting of remarkable structures, resembling in appearance internally flat staves (*e*), placed side by side like the keys of a piano (*inner rods of Corti*). Immediately outside these are a row of groves or depressions (*f*), through which minute continuations of the nerves pass to be connected with these organs (*Habenula perforata* of Kölliker). External to these are a row of flat transparent staves (*middle rods of Corti*), and external to these again are another row (*outer rods of Corti*) (g, i). A vertical section shews that the inner rods point upwards and outwards, so as to meet and slightly overlap the outer rods, which point in the opposite direction, like the beams of a roof. On the surface of these last, project three or more ganglionic nucleated cells, connected with them and one another by delicate jointed processes (k). Outside this complicated nerve apparatus, is the *zona pectinata* of the *lamina spiralis*, which terminates in the spiral ligament (*ligamentum spirale*), a structure described by Bowman, to pass externally into a mass of non-voluntary muscular fibres, called by him the *cochlear muscle.* The exact function of these parts as yet only admits of speculation, although it is impossible to doubt that the rods and terminal cells described by Corti, admit of movement on one another, and that any sonorous undulation communicated to them must cause them to vibrate, and so influence the nerves in connection with them. Further, their analogy to the bacillary membrane of the retina, leads to the supposition, that like the latter, they are the most essential parts of the ganglionic apparatus.

The labyrinth.—In man, sonorous vibrations reach the labyrinth in two ways :—1st, Through the external ear ; and 2d, Through the bones of the head. The ticking of a watch is heard as distinctly when placed between the teeth as when applied to the ear, and the note of a tuning-fork, when it can be no longer heard by the ear, again gives rise to sound when placed in contact with the teeth. It is by the direct vibration of the bones of the head also that we become cognisant of the sound of our own voices. It has been suggested that the cochlea is that part of the labyrinth more immediately connected with those direct vibrations ; whilst the vestibule and semicircular canals is that portion of it which enables the nerve to receive vibrations from without, indirectly, through the air. (Weber.) The constant position of the semicircular canals led Autenreith and Kerner to suppose that they are the parts concerned in conveying a knowledge of the *direction* of sounds. Their elaborate observations on animals, however, admit of such latitude of interpretation, according to the ingenuity of the experimenter and the theory he desires to support, that little reliance can be placed upon them. Wheatstone, however, supports the same idea, on the ground that the semicircular canals being placed in planes at right angles with each other, are affected by the sound transmitted through the bones of the head with different degrees of intensity, according to the direction in which the sound is transmitted. Nothing certain is ascertained on this point.

Impressions made on the auditory nerves in the labyrinth, remain a certain time, like those made on the retina. This was shewn by Savart, by holding a card against the edge of a rapidly rotating toothed wheel. He found that the removal of one tooth did not produce any interruption in the sound. The production of musical notes—that is continuous sounds caused by repeated vibrations—demonstrates the same fact. (See p. 130.)

External ear.—*The auricle* serves to collect the waves of sound and convey them through the short channel, or *meatus*, to the membrane or drum of the ear (*membrana tympani*), which closes it internally. Its function is well observed in man, who places his hand behind the ear when he desires to intensify hearing, by collecting the vibrations of sound. Treviranus thought that the elevations and depressions on the surface enabled him to judge of the direction of sounds, but it is now generally believed that the vibrations impinged upon the external ear, are constrained by them to follow a certain course. In the lower animals, in whom it is largely developed, as in solipeds, ruminants, and cheiroptera, the loss of the auricle often causes partial deafness, but in man it does not seem to be so necessary. I knew an officer who had the auricle removed at the battle of Waterloo by a sabre cut, but who heard ever after on the mutilated side perfectly well. In the *meatus* a number of ceruminous glands pour out a waxy secretion of a bitter taste, which, with the hairs that grow from it, serve as a very sufficient protection from foreign bodies, and especially insects.

Middle ear.—The *membrana tympani*, or drum of the ear, is connected with one end of a chain of small bones (called the *malleus*, *incus*, and *stapes*) which pass across the middle ear, or cavity of the tympanum ; the other being attached to a membrane which closes the oval opening into the cavity of the vestibule (*fenestra ovalis*). Another opening on the same wall, of a round shape, and communicating with the *scala tympani* of the cochlea, is termed the *fenestra rotunda*. These moveable bones render the membranes tense or lax, according to the intensity of the sonorous vibrations impinged upon them. This is accomplished through the agency of minute muscles, especially the *tensor tympani* and *stapedius* muscles, which contract according to the influences transmitted by a series of excito-motory nerves, having for their centre the *otic ganglion.* Hence this part of the apparatus is admirably adapted to carry the nicest vibrations in such a manner as will enable them best to conduce to the production of impressions on the auditory nerve. The cavity of the tympanum or middle ear is filled with air, which passes from the pharynx through the Eustachian tube. This not only permits the free vibration of the chain of ossicles, and equalises the pressure on both sides of the membrane, but further serves to keep the air of a uniform temperature ; a circumstance of the greatest importance to the continuance of good hearing.

There is much similarity between the laws which govern the reception and reflexion of sonorous vibrations and of rays of light ; and, looking at the means necessary to effect this, there is a close analogy between the ear and the eye as organs of hearing and vision. The intensity of light and of sound are both regulated by muscular parts independent of the will, operating through a ganglion and excito-motory nerves ; the ciliary resembles the cochlear muscle, and the reflecting-rods of Jacob's membrane have their analogue in the vibratory rods of Corti attached to the acoustic nerve, where it is expanded on the *lamina spiralis* of the cochlea. So, also, a knowledge of the function of hearing is essentially connected with an acquaintance with certain physical laws which have been previously described. (See p. 129.)

Sense of weight, or a muscular sense.

Much discussion has taken place as to whether a sixth sense exists, viz., a sense of weight, or a muscular sense. Two masses of matter apparently similar may be undetectable by sight or touch, taste or smell, but when balanced in the hands, are at once recognised by their difference in weight. The balance of the body itself under varied conditions, as in walking, riding, hopping, dancing, &c., indicates a peculiar sensibility in the muscles, and a corresponding sensation. "When," says Sir C. Bell, "a blind man, or a man blindfolded, stands upright, neither leaning upon or touching aught, by what means does he maintain his erect position? The symmetry of his body is not the cause. A statue of the finest proportion must be soldered to its pedestal, or the wind will cast it down. How is it, then, that a man sustains the perpendicular posture, or inclines in the due degree towards the wind that blows upon him? It is obvious that he has a sense by which he knows the inclination of his body; and that he has a ready aptitude to adjust the parts of it so as to correct any deviation from the perpendicular. What sense is this? He touches nothing, sees nothing; it can only be by the adjustment of the muscles that the limbs are stiffened, the body firmly balanced, and kept erect. In truth, we stand by so fine an exercise of this power, and the muscles, from habit, are directed with so much precision, and with an effort so slight, that we do not know how we stand. But if we attempt to walk on a narrow ledge, or rest in a situation where we are in danger of falling, or balance on one foot, we become subject to apprehension, and the actions of the muscles are then, as it were, magnified, and demonstrative of the degree in which they are excited."*

In this particular sense, an infant gradually educates itself, as it does in all the other senses. By constant practice there is acquired from its exercise, a peculiar skill and aptitude. It admits of infinite variety, as in active and passive motions, or in adaptation to various purposes with great nicety, as in estimating weight, balancing, throwing weapons, playing on various musical instruments, skilful workmanship, sense of resistance, &c., &c. Like the other senses, it adds largely to our feeling of pleasure and intellectual enjoyment, as may be observed in tossing infants, in the constant tendency to running and active games in the young, in the field sports and gymnastic displays of adults, and in passive locomotion of various kinds by carriage, boat, hammock, &c. Its injury or loss produces that peculiar absence of combining motions for a purpose, while the movements of individual muscles remain, as in the disease now called *Loco-motor ataxia*. Lastly, it has for its special apparatus the muscles, into the fasiculi of which, according to Kühne, nerves enter, and are connected with, oval nuclei, which he supposes to be of a ganglionic nature. (Plate XVI. fig. 11.) On the whole, this sense may, I think, now be considered as fully established.

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* Sir C. Bell on the Hand, 5th edit. p. 238. See also Sir William Hamilton's Dissertations on Reid, p. 864, and Bain, The Senses and the Intellect, p. 85. Lussana. Journ. de Physiologie, 1869.

VOICE AND SPEECH.

Voice is a function of the larynx, while speech is performed by the tongue, lips, and cheeks, in conjunction with the larynx. A description of this organ is purely anatomical. All that need be said is, that it is composed of a tube made up of cartilages, which are connected together by ligaments, and moved upon one another by muscles. In the interior of the tube is a narrow chink in the shape of the letter V, having the point forwards, formed by two folds of membrane called the *vocal cords*, which, thrown into vibration by the air rushing from the lungs, give rise to sound. It thus resembles in construction the mouthpiece of a clarionet or hautboy. Different degrees of tensity are given to these cords ; and the chink, or *rima*, of the glottis is widened or narrowed by the various muscles of the larynx, and by the position of the cartilages. Thus the thyroid cartilage is depressed, and the cords rendered tense by contraction of the *crico-thyroid* muscles ; or by the retraction of the arytenoid cartilages, which are moved backwards by the *posterior-crico-arytenoid* muscles. The cords are approximated by the *arytenoid*, and by the *lateral crico-arytenoid*, while they are separated and the aperture of the glottis enlarged by the *posterior-crico-arytenoid* muscles. The tension of the cords must be regulated to a great extent by the *thyro-arytenoid* muscles which are parallel with them throughout their entire length.

Voice.—Nearly all air-breathing animals possess a voice ; in man and a few birds only can it be so modified as to be capable of producing articulation. The vocal cords are caused to vibrate by the currents of air coming from below, and at once lose this power by destruction of the inferior laryngeal nerves, which, by paralysing the muscles that regulate their necessary tensity, prevents their vibration and the production of sound. These vocal cords, therefore, are the essential parts of the organ of voice. (See Practical Physiology.) Their tensity is varied sometimes by muscular action, and sometimes by the column of air. Thus, to produce low notes they are relaxed, and even wrinkled when at rest, but obtain the necessary degree of stretching by the pressure of the column of air. High notes, on the other hand, are caused by producing great tensity of the cords, and narrowing of the glottis ; and intermediate notes, by intermediate degrees of tensity, and narrowing. The quality as well as the compass of the voice varies in different persons. In the male the deepest is the bass, the highest the tenor, and the intermediate the baritone. The corresponding tones in the female are the contralto, the soprano, and the mezzo-soprano. (See p. 133, Plate VIII. fig. 19.) Many bass voices possess high notes, but the same high note sounded by a bass and a tenor, or by a contralto and a soprano voice, differ in quality or tone, in the same manner that a note sounded by claironet and a flute does. It is the quality, therefore, and not its scale, which constitutes the distinction between voices, the cause of which is unknown.

In men, owing to the prominence of the thyroid cartilage, the vocal cords are longer than in the female, as 3 to 2 ; and his voice in consequence is deeper, and in the musical scale an octave lower. Boys have treble voices, like women ; but as manhood approaches, the thyroid cartilage undergoes a change in its form, and while doing so the voice is cracked or broken. Afterwards it becomes manly and deep ; so that the highest soprano of a boy may be converted into the deepest bass of the man. Male voices also possess two series of notes,—chest or true notes, and false or *falsetto* notes. How the latter are produced is unknown. The strength of the voice does not so much depend upon the current of air as upon the strength and accuracy of the muscular movements regulating the vocal cords. Hence why practice, which gives accuracy and tone to the muscles, is of such importance in the schools of singing. Considering that the muscles which move the cords are only about three-fourths of an inch in length, and how they must adapt themselves in producing notes, semitones, and intervals, it has been calculated that their movements can be varied with the greatest precision to the 1·1200th to the 1·2000th of an inch.

The intonation of the human voice produces an effect on the mind wholly different from that which the mere *meaning* of words excite. The speech of an accomplished orator rouses an audience to a degree of enthusiasm which those who read it in the papers next morning cannot understand. Hence great orators, as great actors, must be seen and heard to be appreciated. Children and animals are affected by our voices, though incapable of understanding our words. The same phrase may be made to present different meanings by simply varying the tone in which it is uttered. This is why those who repeat strictly our words may calumniously falsify our sentiments. That which was spoken originally may have been innocent enough, but the manner in which it is repeated may render it significant and offensive. It is this circumstance which creates half the calumnies circulated among society.

Speech.—The voice, so modified by the additional action of the tongue, cheeks, and lips, as to signify objects, actions, and the properties of things, constitutes language. Languages vary greatly as to the sounds which enter into them, and hence the difficulty persons who have been educated in one, experience in learning others. Words, however, may be produced by the mouth and fauces alone, without the voice. This is whispering. Hence there may be speech without voice, as there is voice without speech. Vocal language, however, can only be accomplished by the combined use of the laryngeal and oral apparatuses. Articulate sounds are divided into vowels and consonants. Vowels are formed in the larynx, whilst consonants are produced in the air-passages above it. Many of these last, however, cannot be uttered unless the elements of a vowel are pronounced with them consonantly ; hence their name. Thus *g* and *k* are formed of the vowels *e* and *a*, modified by the oral aperture. It is by different degrees in the opening and contraction of the mouth and oral canal that most continuous sounds are formed ; others are sudden and momentary, cannot be sustained, and are called explosive sounds, such as *b*, *p*, *d*, and *g*. Hence they are difficult to pronouce well in singing ; and this is why the Italian language, in which they are seldom heard, is so much better adapted to songs than English or German.

The office performed by the mouth in the pronunciation of vowels has been well analysed by Kratzenstein and Kemplin, who have pointed out what the conditions necessary for changing the same sound into different vowels or differences in the size really are. For the utterance of certain vowels, both the opening of the mouth and of the space between the tongue and palate (oral cavity) must be large ; for the pronunciation of others both must be contracted ; and for a third, one must be wide and the other contracted. They give five degrees of size, the dimensions of which vary by closure of the oral opening and the space between the tongue and palate as follows :—

Vowel.	Sound.	Size of oral opening.	Size of oral canal.
a	as in far	5	3
a	,, name	4	2
e	,, theme	3	1
o	,, go	2	4
oo	,, cool	1	5

When the laryngeal and oral parts of the organ of speech cannot be combined, some letters, especially the explosive ones, as *t* and *p*, are not consonant with the vowel ; and *stammering* is the result. It is to be corrected by a careful study of the mode of pronouncing the various consonants, with constant practice—avoiding hurry and nervous agitation, which render all muscular action uncertain. *Ventriloquism* is speaking without giving external evidence of utterance, and keeping the oral aperture immoveable while the attention of the audience is directed as much as possible to the thing or place from which the voice is supposed to come.

The Layrngoscope.—The appearance and actions of the larynx during phonation and respiration, can now be rendered visible by means of the laryngoscope, for a description of which, its mode of application and results, see Practical Physiology.

Sleep—Dreams—Somnambulism—Mono-ideism.

Sleep is that temporary suspension of the cerebral functions which in animals alternates with their exercise for a certain time, which suspension, however, is capable of interruption on the application of stimuli to the sensory nerves. Unless this last condition could be carried out, the individual would labour under coma, syncope, or asphyxia,—states more or less allied to sleep. All action in the living economy produces waste of tissue ; and hence the necessity of rest in order that substance may be added. The cerebral functions, especially, are governed by this law, and we are obliged to submit to their suspension for a certain period, which is natural sleep. On awakening, we feel refreshed ; greater strength is imparted to the muscles, higher sensibility to the nerves, and greater power to the mind. Sleep is more or less profound according as the body is more or less fatigued, and according to the constitution of the individual; as in some persons it is naturally light, whilst in others it assumes a soporose character. Habit and temperament also exert a strong influence over sleep, some persons falling into or arousing from it at particular hours, independent of all other circumstances. Its invasion may be sudden or gradual. As a general rule, the senses and reasoning faculties sleep first, whilst imagination and the lighter ones remain longer awake. We may also awake suddenly; but there is usually an intermediate condition between sleep and waking. It is in these intermediate conditions that the sleep is lightest, and that persons can be aroused with the greatest facility. The amount of sleep required by man varies according to age, temperament, habit, and previous fatigue. In infancy and extreme old age, life is almost a continuous sleep. In adults there is no rule, some persons requiring more and some less. The average period spent by mankind in sleep is eight hours in the twenty-four, being one-third of human life.

Dreams.—Not unfrequently while some mental faculties are suspended others are still active, and are busy with numerous ideas, which succeed each other with more or less regularity. This is dreaming. There is an absence of consciousness regarding external things, and a want of control in regulating the current of thought; so that the principle of suggestion—that is, one thought calling up another in a certain sequence—has unlimited governance of the mind. In some rare cases the dreaming thoughts are very consistent and vivid, but generally speaking they are more or less confused or incongruous. Not unfrequently, when seemingly in danger, we are governed by an intense desire to escape from it, while we possess an agonising consciousness that we have not the slightest power to do so. This is *incubus*, or nightmare. Another curious circumstance is the rapidity with which, when dreaming, trains of thought pass through the mind, the events of years being apparently compressed into moments. The most mentally agitating dreams need not occasion the slightest change of position or muscular movement, although sometimes they produce restlessness, various gestures, or emotional indications. But when the ideas of a dream govern the motions and conversation of an individual, while the memory and other faculties of the mind are still so suspended that on awakening he is quite unaware of what has occurred, the condition is called *somnambulism.*

Theory of sleep and dreams.—Many opinions have been advanced as to the condition of the brain during sleep and dreaming, most of which assume a state of congestion to be the cause. If this be general and equal, sleep results ; if partial,—that is, more intense in places where particular faculties of the mind may be supposed to exist,—the result is dreaming. In the vast majority of cases, all illusions and delusions, like sleep, are the result of exhaustion, long watching, ill health, grief, intense excitement, and of narcotic drugs which depress nervous force. The old are much more subject to them than the young. In all these cases the pulse becomes quick and feeble, and considering what has previously been said as to the peculiar circulation within the cranium (p. 220), it will be readily understood how this is deranged. Some have supposed that the choroid plexuses enlarge and become erectile, so causing pressure. Others, that the vaso-motor system of nerves influence the cerebral vessels ; and that as the grey substance is most vascular, so that portion of it we have seen to be most intimately connected with mind (p. 284), is the one most readily affected.

Somnambulism.—The peculiarity of this state consists in the mind being wholly occupied with one idea or train of thought, to the exclusion of all other considerations. Thus there may be complete insensibility to bodily pain, to loud sounds, flashes of light, or other ordinary stimuli, although whatever is spoken or done in harmony with the subject thought of, is heard and appreciated, often with unusual acuteness. We can frequently change the current of the ideas by audibly suggesting others, when all the feelings and emotions in connection with the new subject are called into action, to the exclusion of those which previously existed. Thus, if the attention be strongly fixed on a distant object, impressions made on the skin will not induce sensation ; but if the attention be directed to the skin, its sensibility often becomes wonderfully excited, and pain is experienced from the contact of bodies that, under ordinary circumstances, would scarcely be felt. The same rule applies to all the other senses. In the same manner the reasoning power is often increased on a particular point, and a variety of things performed, or movements gone through, that the individual otherwise could never have accomplished. Some men perform all the acts which at the time are suggested to them, or describe the various scenes which in imagination are placed before them.

In this way a somnambulist may be made not only to think and converse on any subject, but to go through any kind of action, however ridiculous or even fatiguing. He will place himself under every variety of condition presented to his mind, and perform the appropriate motions, as well as give utterance to the ideas, which such conditions would naturally give rise to. Thus, he may be made to hunt, swim, fight, appear intoxicated, visit distant cities or lands, &c. None of these acts and ideas are remembered in the ordinary waking condition, although when again thrown into a similar state, they may be taken up and continued. Such a person may be said to have two kinds of memory,—one when awake, and one when dreaming; or, as it has been called by some, a *double consciousness.* Somnambulism may come on involuntarily, at regular or irregular periods, or it may be excited artificially. In either case it may be accompanied by various nervous phenomena, denominated *catalepsy, trance, ecstacy,* and so on.

Mono-ideism.—Dreaming and the phenomena of somnambulism may be excited in some persons artificially, when the acts of the mind, sensation, and motion may be completely governed by means of suggestive ideas, even although the individual be conscious. This state has been called *mono-ideism.* (Braid.) The mode of effecting this is to cause a certain number of persons to fix their attention on a small object, as a coin, or submit to have monotonous passes made with the hands before their face. On an average, at least one person in twenty so treated feels in a shorter or longer time, first a mistiness of vision or stiffness in the eyelids, and occasionally deep-drawn sighs, hurried respiration, and signs of general excitement are visible. If now such persons are respectively told in a confident manner that they cannot open their eyes, it will be found that they cannot do so, especially if their attention be more strongly directed to the eyelids by touching or by pointing to them. But on receiving permission, or on being commanded to open them, this is done at once. Such persons may now, as in certain cases of somnambulism, have every kind of motion, sensation, or mental act produced, governed, or arrested, according to the endless train of suggestive ideas that may be communicated to the individual. Many of the lower animals also appear to be susceptible of being impressed by what strongly arrests their attention, in such a way that they are rendered incapable of voluntary motion, or irresistibly impelled towards the object. Hence the long glittering bodies of serpents, or the glaring eyes of other animals, *fascinate* birds and small quadrupeds, and render them an easy prey to their enemies. Similar effects are produced in individuals who look from heights and precipices, and experience an uncontrollable desire to leap down, although it be to certain destruction.

Like phenomena have occurred in all ages, produced in certain persons by predominant ideas, and variously modified according to the education, politics, or religion of the period. Thus the effects produced on many votaries during their initiation into the ancient mysteries ; the ecstacies of the Pythian and other priestesses ; the influence of religious enthusiam ; the dancing epidemics of St Vitus or of Tarantism in the middle ages ; the hallucinations of the Convulsionaires at the tomb of St Medard, in Paris ; the effects of magic and of spells, &c., &c., are of the same character. Numerous perversions of the nervous functions, identical in their nature with those described, consisting of sensory illusions, muscular convulsions or rigidity, and peculiar trains of thought influencing acts and conversation, may be found in the histories of witchcraft and demonology, in the legends of the saints, the journal of Mr Wesley, and in the accounts given by travellers of the religious camp-meetings in the woods of America. They are perhaps more common now than formerly, and excite even more astonishment among the ignorant ; the only difference being, that the same phenomena, which in a dark age were attributed to divination or incantation, now assume the garb of science, and are ascribed to magnetism or electricity.

It is unnecessary to enter into any lengthened argument to refute the numerous hypotheses which ascribe these effects to external influences. There is no series of well-ascertained facts capable of supporting such a doctrine ; whereas it would be easy to prove that all the phenomena really occasioned depend on suggestive ideas communicated to the person affected. But while these theories scarcely merit attention, the facts themselves are highly important, and demand the careful consideration of the physiologist and medical practitioner. The effect of mind on the body has from the earliest periods been seized upon by individuals as a ground for veneration or astonishment. In ancient times the heathen priests were the physicians, and the temples were converted into so many dispensaries, at which the sick applied for relief. In Catholic countries, during the middle ages, the offices of priest and physician were frequently united in one person ; so that the powerful effects of certain shrines, and the benefits of pilgrimages in cases not admitting of simple cure, met with every encouragement. From what has preceded, it must be allowed that, so far from its being improbable that real cures were so effected, all that we know of the effects of confident promises on the one hand, and belief on the other, render it very likely that many such occurred. The legends of the saints, the history of witchcraft, the journal of Mr Wesley, the accounts of celebrated pilgrimages, and of the virtues of particular shrines, and the writings of religious enthusiasts generally, abound in wonderful cures. Charms, amulets, and relics are stated to have at once banished all kinds of agony, and removed numerous nervous diseases. Many of these are certainly incredible, whilst others are perfectly conceivable. The benefits of the royal touch are confirmed by the observations of Richard Wiseman, and the cures performed by Greatrakes are warranted by Robert Boyle. In all these cases, there can be little doubt that any benefit which did occur may be attributed to a strong belief, on the part of the patient, in the efficacy of the means employed. The facts ascertained in connection with this subject open up a wide field for investigation, not only in physiology and practical medicine, but in what relates to evidence as it is now received in courts of law.

As regards the nature of this condition, it seems analogous to that of sleep or dreaming, in which certain faculties of the mind are active, and may be even stimulated into excessive action, whilst others are suspended. All the phenomena produced are strictly analogous to what medical men are acquainted with in various morbid states ; and it must now be considered as well established, that in certain conditions of the nervous system they may be induced at will. This conclusion, however, is something new, for it has but recently been received in physiology or pathology, that a condition of the cerebral functions may be occasioned in apparently healthy persons in which suggestive ideas are capable of producing those phenomena we have described, and which render them, for the time, as irresponsible as monomaniacs. Yet such is really the fact, and once admitted into physiology, must have an important influence on the theory and practice of medicine. Such a condition may probably be accounted for physiologically in the following manner :—

We have previously seen that the white matter of cerebral lobes contain tubes, which run in three directions,—1st, Those which pass from below upwards, and connect the hemispherical ganglion with the spinal cord ; 2d, Those which pass transversely, forming the commissures, and which unite the two hemispheres ; and 3d, Those which run from before backwards, uniting the anterior with the posterior lobes on each side. It has also been stated that these tubes are probably subservient to that combination of the mental faculties which characterises thought. Now, all metaphysicians and physiologists are agreed that the mind is composed of various faculties, and that different portions of the nervous mass are necessary for their manifestation. True, it is by no means determined what or how many faculties mind should be divided into ; still less is it known which parts of the brain are necessary for the manifestation of each. But let the first proposition be granted, then there is no difficulty in supposing that one or more of these may be paralysed or suspended, whilst others are entire, any more than there is in knowing that sensation may be lost whilst motion remains intact, although the nerve fibres of both run side by side. It may be presumed, then, that certain mental faculties are, as the result of exhausted attention, temporarily paralysed or suspended, whilst others are rendered active in consequence of being stimulated by suggestive ideas ; that the psychical stimuli of the former make no impressions on the cerebral conducting tubes, whilst those of the latter are increased in intensity ; that the proper balance of the mind is thereby disturbed, and thus the individual, for the time being, acts and talks as if the predominant idea was a reality. The condition is analogous so far with ordinary somnambulism, certain forms of hypochondriasis, and monomania, but admits of infinite changes, from the nature of the idea suggested.

According to this theory, therefore, we suppose that a psychical stimulus is generated, which, uncontrolled by the other mental operations acting under ordinary circumstances, induces impressions on the peripheral extremities of the cerebral fibres, the influence of which only is conveyed outwards to the muscles moved. In the same manner, the remembrance of sensations can always be called up by the mind ; but under ordinary circumstances we know they are *only* remembrances, from the exercise of judgment, comparison, and other mental faculties; but these being exhausted, in the condition under consideration, while the suggested idea is predominant, leave the individual a believer in its reality.

In this manner we attribute to the faculties of the mind a certain power of correcting the fallacies which each is liable to fall into, in the same way that the illusions of one sense are capable of being detected by the healthy use of the other senses. We further believe that the apparatus necessary for the former operations consists of the nerve-tubes which unite different parts of the hemispherical ganglion, whilst that necessary for the latter are the nerve-tubes connecting together the organs of sense and the ganglia at the base of the encephalon. A healthy and sound mind is characterised by the proper balance of all the mental faculties, in the same manner that a healthy body is dependent on the proper action of all the nerves. There are mental and sensorial illusions, one caused by predominant ideas, and corrected by proper reasoning; the other caused by perversion of one sense, and corrected by the right application of the others. Both these conditions are intimately united, and operate on each other, inasmuch as voluntary and emotional movements and sensation are mental operations.

This theory, if further elaborated, appears to be consistent with all known facts, and capable of explaining them on physiological principles.

ABNORMAL INNERVATION.

The derangements of the nervous system like those of nutrition, can never be understood without a knowledge of its anatomy and physiology. The general laws which regulate the morbid actions it evinces, have been referred to (p. 289). The special disorders may be classified into:—1st, Cerebral; 2d, Spinal; 3d, Cerebro-spinal; 4th, Neural; and 5th, Neuro-spinal, according as the brain spinal cord, or nerves are affected alone, or in combination. Aberrations of intellect always depend on cerebral disturbance, while preversions of motion and sensibility, if extensive, indicate spinal, and if local, neural disorder. Thus, insanity and apoplexy are cerebral; tetanus and chorea, spinal; epilepsy and catalepsy are cerebro-spinal;

neuralgia and local paralysis are neural; and all combined spasms, dependent on diastaltic or reflex actions, are neurospinal. The following is an enumeration of nervous disorders, with the meanings that ought to be attached to them.

Classification of Diseases of Innervation.

I. *Cerebral Disorders, in which the cerebral lobes (or brain proper) are affected:—*

INSANITY, or mental aberration in its various forms, include *partial* and *general* insanity. The first comprehends *Monomania*, or madness on one particular subject, *Instinctive* or *Impulsive Insanity*, *Moral Insanity*, and *Hypochondriasis.* The last comprehends *Mania*, or raving madness, *Dementia* or diminution, and *Amentia*, total loss of the mental faculties.

HEADACHE and other uneasy sensations within the cranium, such as lightness, heaviness, vertigo, &c., &c.

APOPLEXY.—Sudden loss of consciousness and of voluntary motion, commencing in the brain. The absence of consciousness necessarily involves that of sensation. The same condition as regards nervous phenomena exists in *syncope* and *asphyxia*, but the first of these commences in the heart, and the second in the lungs. Allied to apoplexy is *coma* or stupor, arising from various causes affecting the brain, such as pressure, or poisonous agents like alcohol, chloroform, opium, &c., &c.

TRANCE, or prolonged somnolence, either with or without perversion of sensation or motion. To this state is allied *ecstasy*, or unconsciousness with mental excitement.

IRREGULAR MOTIONS, SPASMS, &c., originating in excited or diminished voluntary power, as in certain cases of *dominant ideas*, *somnambulism*, *saltatory movements*, *tremors*, &c.; or, on the other hand, *incapability of movement* from langour, surprise, mental agitation, &c., &c.

II. *Spinal Disorders, in which the cranial and vertebral portions of the spinal cord are affected:—*

SPINAL IRRITATION.—Pain in the spinal column, induced or increased by pressure or percussion, often associated with a variety of neuralgic, convulsive, spasmodic, or paralytic disorders affecting in different cases all the organs and viscera of the body, and so giving rise to an endless number of morbid states.

TETANUS.—Tonic contraction of the voluntary muscles. *Trismus*, if confined to the muscles of the jaw; *Opisthotonos*, if affecting the muscles of the back, so as to draw the body backwards; *Emprosthotonos*, if affecting the muscles of the neck and abdomen, so as to draw the body forwards; and *Pleurosthotonos*, if affecting the muscles of the body laterally, so as to draw the body sideways.

CHOREA.—Irregular action of the voluntary muscles, when stimulated by the will.

HYSTERIA.—Any kind of perverted nervous function, connected with uterine derangement. Nothing can be more vague than this term.

HYDROPHOBIA.—Spasms of the muscles of the pharnyx and chest, with difficulty in drinking and dread of fluids.

SPASMS AND CONVULSIONS.—Tonic and clonic contractions of the muscles of every kind and degree, not included in the above, originating in the cord. (Centric Spinal Diseases—Marshall Hall.)

HEMIPLEGIA.—Paralysis of a lateral half of the body, generally dependent on disorders of the cranial portion of the spinal cord above the decussation in the *medulla oblongata.*

PARAPLEGIA.—Paralysis on both sides of the body, generally the lower half, in consequence of disorder of the vertebral portion of the spinal cord, below the decussation in the *medulla oblongata.*

III. *Cerebro-Spinal disorders, in which both cerebral lobes and spinal cord are affected :—*

EPILEPSY.—Loss of consciousness with spasms or convulsions occurring in paroxysms. *Apoplexy with convulsion or paralysis* is also cerebro-spinal.

CATALEPSY.—Loss of consciousness with peculiar rigidity of muscles, so that when the body or a limb is placed in any position it becomes fixed.

ECLAMPSIA.—Tonic spasms with loss of consciousness in infants. The acute epilepsy of some writers.

IV.—*Neural disorders, in which the nerves are affected during their course or at their extremities :—*

NEURALGIA.—Pain in the course of a nerve, although in fact all kind of pain whatever is owing to irritation of the nerves.

Thus the sympathetic system of nerves and its ganglia, though ordinarily giving rise to no sensation, may occasionally do so, as in *angina pectoris*, *colic*, *irritable testicle and uterus*, and in other agonizing sensations, referred to various organs.

Irritation of the Nerves of Special Sense.—Of the optic, causing *flashes of light*, *ocular spectra*, *muscæ volitantes*, &c.; of the auditory, causing *tinnitus aurium ;* of the olfactory, causing unusual *sensitiveness to odour;* and of the gustatory, causing *perverted tastes* in the mouth. Itching, formication, and other sensations referable to the peripheral nerves, also belong to this class.

Irritation of Special Nerves of Motion, as in local spasms of one or more muscles, or of the hollow viscera.

Local Paralysis.—Loss of motion or sensibility in a limited part of the body, or confined to a special sense, as in *lead palsy*, or in *amaurosis*, *cophosis*, *anosmia*, *ageustia*, *anæsthesia*, and *locomotor ataxia.*

V. *Neuro-spinal disorders, in which both the nerves and spinal cord are affected :—*

Diastaltic or Reflex Actions.—To this class belong all those diseases depending on irritation of the extremity of a sensitive nerve, acting *through* the cord and motor nerves on the muscular system, and producing a variety of spasmodic disorders, local or general, far too numerous to mention—which can only be understood by a thorough knowledge of the physiology of the diastaltic or excito-motory system of nerves.

All these disorders may be the result of structural disease of the nervous system, or of what is called *functional derangement*, understanding by this a disease which, even when it causes death, leaves no trace of altered structure detectable with the aid of the microscope. Thus, tetanic rigidity may depend on a spinal arachnitis, as well as on the irritation from a wound or poisoning by strychnine ; and delirium and coma may be caused by cerebral meningitis, as well as by moral insanity, starvation, or poisoning by chloroform or opium. Whether in these cases there be in fact only one cause common to the whole, it is difficult to say ; certainly it cannot be demonstrated. It might be contended that in every instance there is a certain amount of congestion producing unaccustomed pressure, or that a peculiar state of nutrition of the part is momentarily produced here or there in the nervous mass. But as neither theory appears to us applicable to all cases, we shall consider the *pathological causes of nervous disorders* as of four kinds,—1st, Congestive; 2d, Structural; 3d, Diastaltic; 4th, Toxic.

1. *Congestive derangements of the nervous system.*—The peculiar nature of the circulation within the cranium and vertebral canal has been previously pointed out (p. 220), and we have seen that, although well defended under ordinary circumstances against any mischievous change, still, when such change does occur, it operates in a peculiar manner. In other words, so long as the bones are capable of resisting atmospheric pressure, although the amount of fluid within these cavities cannot change as a whole, yet the distribution of that amount may vary infinitely. Thus, by its being accumulated sometimes in the arteries, at other times in the veins, or now in one place and then in another, unaccustomed pressure may be exercised on different parts of the nervous centres. This, according to its amount, may either irritate or suspend the functions of the parts; a fact proved by direct experiment, as well as by innumerable instances where depression of bone has caused nervous phenomena which have disappeared on removal of the exciting cause. That congestion does frequently occur in the brain and spinal cord there can be no doubt, although it cannot always be demonstrated after death. The tonic contraction of the arteries is alone sufficient to empty them of their contents, and turgidity of the veins may or may not remain according to the symptoms immediately preceding death, and the position in which the body is placed. But it is observable that those causes which excite or diminish the action of the heart and general powers of the body are at the same time those which induce nervous disturbance, as well as occasion a change of circulation in the cerebro-spinal centres—such as the emotions and passions, plethora and anæmia, unaccustomed stimuli, uterine derangement, &c.

It is only by this theory that we can understand how such various results occasionally occur from apparently the same cause, and again how what appear to be different causes produce similar effects. Thus, violent anger, or an unaccustomed stimulus may, in a healthy person, induce a flushed countenance, increased action of the heart, a bounding pulse, and sudden loss of consciousness. Again, fear or exhaustion may occasion a pallid face, depressed or scarcely perceptible heart action, feeble pulse, and also loss of consciousness. In the first case, or ***coma***, there is an accumulation of blood in the arteries and arterial capillaries, and a corresponding compression of the veins ; in the second case, or *syncope*, there is distension of the veins and venous capillaries, with proportionate diminution of the calibre of the arteries. In either case, owing to the peculiarity of the circulation within the cranium, pressure is exerted on the brain. Hence syncope differs from coma only in the extreme feebleness of the heart's action,—the cause, producing loss of consciousness, sensation, and voluntary motion, being the same in both. Indeed, it is sometimes difficult to distinguish these states from each other ; and that they have frequently been confounded, does not admit of doubt.

In the same manner, partial congestion from either cause may occur in one hemisphere, or part of a hemisphere, in the brain, or in any particular portion or segment of the spinal cord. The pressure so occasioned may irritate and excite function, or may paralyse or suspend it ; nay, it may so operate as to suspend the function of one part of the nervous system, while it exalts that of another. Thus all the phenomena of epilepsy are eminently congestive, the individual frequently enjoying the most perfect health in the intervals of the attack, although the effects are for the time terrible, causing such pressure that, while the cerebral functions are for the time annihilated, the spinal ones are violently excited. In the same manner are explained all the varied phenomena of hysteria and spinal irritation, for inasmuch as the spinal cord furnishes, directly or indirectly, nerves to every organ of the body, so congestion of this or that portion of it may increase, pervert, or diminish the functions of the nerves it gives off, and the organs which they supply. Congestion, therefore, we conceive to be the chief cause of functional nervous disorders originating in the great cerebro-spinal centre.

2. *Structural derangements of the nervous system.*—The various parts of the nervous system, being furnished with blood vessels, are subject to most of the diseases of nutrition. The brain and spinal cord are especially liable to those lesions which produce

effusion, extravasation, exudation, morbid growths, and degenerations of texture. The effects these occasion are identically the same in kind as those caused by simple pressure, or from the other circumstances to be referred to. In their mode of onset, however, they exhibit a difference. Thus, as a general rule, hæmorrhage is indicated by suddenness of attack ; acute exudations, by local pain, with fever ; chronic exudations and tumours, by gradual perversion of the mental, sensitive, and motor functions in various ways and degrees, according to the part affected. Intelligence suffers in proportion to the extent and nearness of the disease to the hemispherical ganglion, and motion according as the cerebral and vertebral portions of the spinal cord are influenced. Occasionally, after more or less impairment of intellect, sudden paralysis appears ; a result attributable to the rupture or deliquescence of tubes which have been already softened, but not sufficiently so to interrupt their power as conductors of the nervous force. Instances, indeed, have been recorded where complete destruction of one half of the brain, or of the whole thickness of the spinal cord is said to have occurred, in which no paralysis or other symptom has been caused ; but it is certain that numerous tubes in such cases were intact during life, and capable of transmitting impressions.

3. *Diastaltic or reflex derangements of the nervous system.*—We have previously seen (p. 289) that recent researches render it probable that the actions hitherto denominated *reflex* are in fact direct ; only that the impression which is conveyed commences in the circumference of the body, instead of in the nervous centres. There is every reason to believe that such impressions pass *through* the cord by means of conducting nerve fibres, which cross from one side of that organ to the other, and that histology will yet demonstrate that all these apparently confused actions are dependent on the existence of certain uniform conducting media. Indeed, already we can judge with tolerable exactitude from the effects, what are the particular nerves and segments of the cord which are influenced during a variety of actions ; and notwithstanding the immense difficulties of the inquiry, we have every hope that the period is not distant when the diagnosis of many more reflex acts will also be rendered certain. The principle involved in all these acts is, that

the irritation which produces them is to be sought for in the nervous extremities rather than in lesions of the centres ; and the great importance of this principle in pathology and in practice cannot be too highly estimated, although, for the numerous details which illustrate it, we must refer to a previous part of this book (p. 312), and especially to the works of Dr Marshall Hall. We would point to traumatic tetanus, and to the convulsions resulting from teething and gastric derangements in children, as good examples of diastaltic functional disorders. Numerous symptoms which accompany organic changes belong to the same category. In other words, the structural lesion constitutes the irritant, or cause, while the effect is functional.

4. *Toxic derangements of the nervous system.*—The influence exercised by certain drugs is of a kind which causes a close resemblance to various diseases of the nervous system. These influences, if carried to excess, are toxic, and dangerous to life ; if employed moderately, and with caution, they constitute the basis of our therapeutic knowledge in a vast variety of diseases. Why one drug should possess one power, and another a different one,—or why some should influence the brain, and others the spinal cord or nerves,—we are ignorant. Such facts are as much ultimate facts in therapeutics as are the separate endowments of contractility and sensibility in physiology. As pathological causes of functional disorders of the nervous system, their power is undoubted. By their means the five classes of nervous disorders may be occasioned in different ways, producing altogether distinct and peculiar effects. Thus—

Toxic cerebral derangements are occasioned by *opium* and most of the pure narcotics, which first excite and then depress or destroy the mental faculties. According to Flourens, *opium* acts on the cerebral lobes, while *belladonna* operates on the *corpora quadrigemina.* The first causes contraction, and the last dilatation of the pupils. *Tea* and *coffee* are pure excitors of the cerebral functions, and cause sleeplessness. *Alcoholic drinks, æther, chloroform,* and similar stimulants, first excite and then suspend the mental faculties, like opium. The modern practice of depriving persons of consciousness, in order for a time to destroy sensation, has been very much misunderstood in consequence of such remedies having been erroneously and unscientifically denominated anæsthetics. The fact is, they in no way influence local sensibility, or the sense of touch. Their action is altogether cerebral; and hence the danger which has frequently attended their action.

Toxic spinal derangements.—*Strychnine* acts especially as an excitor of the motor filaments of the spinal cord, causing tonic contractions of the muscles, as in tetanus from spinal arachnitis, or from the diastaltic action of a wound. *Woorara* produces exactly an opposite effect, causing paralysis and flaccidity of the same parts. *Conium* paralyses the motor and sensitive spinal nerves, producing paraplegia, commencing at the feet, and creeping upwards.* *Picrotoxine*, according to Dr Mortimer Glover, causes the animal to stagger backwards, as in the experiments of Magendie or the *crura cerebelli.*

Toxic cerebro-spinal derangements.—Of these, the poisonous effects of *hydrocyanic acid* offer a good example. All the animals we have seen killed by this agent utter a scream, lose their consciousness, and are convulsed. These are the symptoms of epilepsy. *Cold* is at first an excitor of the spinal functions, and is a strong stimulant to diastaltic activity, but if long continued, produces drowsiness and stupor.

Toxic neural and neuro-spinal derangements are especially occasioned by the action of certain metallic poisons, such as *mercury*, which occasions irregular muscular action, with weakness; and *lead*, which causes numbness and palsy, most common in the hands. On the other hand, *cantharides* stimulates the contractions of the neck of the urinary bladder and *secale Cornutum* those of the pregnant uterus. *Stramonium* acts as a sedative to the nerves of the bronchi; while *aconite* operates powerfully in paralysing the action of the heart.

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* See the author's case, in which the symptoms resembled those caused in Socrates as described by Plato. Ed. Med. and Surg. Journal, 1845, and Clinical Medicine, 5th edit. p. 459.

REPRODUCTION.

The process whereby the countless variety of organisms which constitute the vegetable and animal worlds is perpetuated on the surface of the globe has from the earliest periods attracted the attention of physiologists, naturalists, and philosophers. In recent times, the excellence of the achromatic microscope has enabled us to penetrate much further into the mysteries involved in reproduction, and the whole subject is now one of vast extent.

We shall speak of this function as consisting of three kinds, viz.: first, Homogenesis; second, Parthenogenesis; and third, Heterogenesis.

HOMOGENESIS.

By Homogenesis (*ὁμοιος*, like; *γενέσις*, generation) is to be understood the production of offspring resembling in form that of their parents. This mode of reproduction is the only one found in man and the higher animals. The process may be divided into three stages: first, the production and discharge of germs; second, the fecundation of these germs; and third, the changes which follow fecundation.

The Production and Discharge of Germs.

We have seen that at the earliest period of development in all organised beings, without exception, there is formed a molecular blastema which originates a nucleated cell (pp. 45 to 49). Up to the point where sexes are manifest, the process of reproduction is identically the same with that of cell growth. The peculiarity of the function of generation in the higher organisms consists in the superaddition to this process of a particular act, whereby the further development of germ-cells is occasioned. There is a special apparatus in animals and in plants—the *ovary,*—the function of which is to mature a germ, that from the time of its first formation is capable of becoming the rudiment or embryo of a new being, and which is often separated from its parent in a form altogether dissimilar to that which it is ultimately to assume. This sometimes takes place as a spore, at others as an egg; and hence the terms *sporuliferous* and *oviparous*, as distinguished from *viviparous* reproduction. The more heterogeneous a structure becomes,—that is, the more difference is manifested in the structure and properties of its separate parts,—the less title has any one to be regarded as a separate individual, since it cannot maintain an independent existence, nor reproduce the entire structure. When an organism merely consists of a multiplication of similar parts, these parts may separate, and constitute independent existences, as in the Algæ among plants, and in the Protozoa and Cœlenterata among animals. When it divides into a number of parts this has been called *fissiparous* generation—a mode of reproduction that never takes place in the more highly organised beings. In other cases, a bud is formed on the parent which may ultimately separate as an independent being. This is termed reproduction by *gemmation.* These modes of propagation are identical with that of multiplication by cells alone, with this difference, that at one period groups of cells are aggregated and united together, and afterwards separate.

Germ-cells are constantly forming and ripening in the ovaries of plants and animals, and are separated from them at particular times. In the separation of these cells, indeed, a tendency to periodicity is manifested. Thus, plants flower at certain seasons—some in spring, others in summer, and a third class in autumn or winter—with great regularity. Throughout the whole range of animals the same thing is observable. They all present a breeding period, at which time alone ova are fully developed, and capable of being fecundated.

Phenomena attending the separation of germ-cells in plants and animals.—The reproductive organs of plants and animals at this time *become elevated in temperature.* Among plants, this is most appreciable in the Arum tribe (Araceæ), where male and female flowers are collected in great numbers on a thick *spadix* or stalk, and are enclosed in a sheathing bract termed a *spathe.* On one occasion, Brogniart observed that in the *Colocasia odora* the temperature was 8° above that of the surrounding air. This was increased in the following day to 18°, and, during the emission of pollen, on the three succeeding days to 20°, after which it began to diminish with the fading of the flower.* In animals, the same elevation of temperature has caused agriculturists to denominate this season the *period of heat.* It originates in them from excessive congestion in the capillaries of the part, causing great local and more or less general disturbance of the system, the result of an augmented nutrition in the ovaries necessary for the complete development of the ova. This congestion causes rupture of the vessels and discharge of blood, which in the human female, and in a few of the monkey tribes, causes an external flow, known as the *menstrual fluid*, while the process in them has received the name of *menstruation*.

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* "Balfour's Class-Book of Botany." 1871. Pp. 519-526.

Menstruation.—This term is applied to the periodical discharge from the female generative organs of a bloody fluid. It occurs in most women once every four weeks, or once every lunar month, hence the term *menses*. It usually appears at a fixed date, and continues from three to seven days. There is then an interval of about three weeks until it again appears. The discharge is often accompanied by general symptoms, such as debility, weariness, pain in the back and limbs. It rarely occurs in pregnant women or during lactation. The quantity of fluid varies in different individuals and at different ages. The essential part of this function, however, is not the discharge of a fluid externally, but the ripening and separation of ova from the ovaries. Multitudes of seeds and of ova are formed in this manner, at regular periods, in plants and animals, which prove abortive, and the history of which is identical with the formation, ripening, and disintegration of simple nucleated cells, which have no power of reproduction.

Microscopic Characters of Menstrual Fluid. — It consists chiefly of mucus which is coagulated by acetic acid, forming molecular fibres. There are also blood corpuscles, and epithelial cells derived from the mucous membrane of the uterus. It cannot be distinguished from blood discharged from any other mucous surface, and the amount of mucus usually prevents it from spontaneously coagulating.

Structure of the Ovaries.—These organs, two in number, in the human female, are situated at the back of the broad ligament of the uterus. They measure, in the unimpregnated condition, one and a half inches in length, three quarters of an inch in breadth, and nearly half an inch in thickness. They consist essentially of a fibrous stroma (Plate XVII. fig. 4) or network, richly supplied with blood-vessels, enclosed in a tough capsule composed of white and yellow fibrous tissue (*tunica albuginea*). In the meshes of the stroma there are developed certain cells termed Graafian vesicles, from De Graaf who first described them.* These appear first, according to Schrön† and Gröhe,‡ near the surface in the ovary of the cat (Plate XVII. fig. 4), and may be seen in great numbers in the ovary of even a newly-born female child. As they increase in size, they pass deeper into the substance of the ovary (Plate XVII. fig. 4), and undergo development, as a result of which ova are formed in their interior. In the ovary of a female at puberty, or during the child-bearing period, Graafian vesicles in all stages of development may be seen (Plate XVII. fig. 4). When the ovum is fully developed, and ready for extrusion, the cavity of the Graafian vesicle enlarges, by the secretion of fluid in its interior, pushes aside the part of the stroma between it and the surface, and projects from it externally.

Structure of the Graafian Vesicle and Ovum.—The manner in which ova are formed in the ovary has been well studied by Martin Barry, who informs us that molecules and granules are deposited in groups among the fibrous stroma of the organ (Plate XVII. fig. 4, *a*, and fig. 5). Around a large granule smaller ones are aggregated, and become surrounded by a membrane—the *ovisac*—so as to form a nucleated cell containing granular matter (Figs. 5, 6, and 7, *a*, *b*). This granular matter now separates into two portions. The inner forms a membrane that immediately surrounds the yolk, and from its transparent appearance has been called the *zona pellucida* (Fig. 4). The outer divides into two layers, one of which, covering the *zona pellucida*, he called the *tunica granulosa* (Fig. 4, *c*) ; and the other, which lines the ovisac, the *membrana granulosa* (Fig. 4, *b*). These two membranes are united together by four or more bands —the *retinacula*—having transparent fluid between them. In the fully formed Graafian vesicle, several of the retinacula disappear, while those remaining become shortened and enlarge so as to form a disk-shaped mass of granules, termed by Von Baer the *proligerous disk*. (See Plate XVII. fig. 4, lower Graafian vesicle.) The whole structure now forms a vesicle,—the *Graafian vesicle*,—and consists externally of a fibrous or vascular membrane, and another inner one—the *ovisac* of Barry—having suspended from it, by the *retinacula*, the ovum composed of *zona*

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* De Graaf, De mulierum organis generationi inservientibus, 1672.

† Schrön, Zeitschrift f. Wissensch Zoologie, vol. xii. p. 409.

‡ Gröhe, Virchow's Archives, vol. xxvi. p. 271; xxix. p. 450.

pellucida, *yolk* (Fig. 4, *d*), and *germinal vesicle* (Fig. 4, *e*). In the interior of the germinal vesicle there is a smaller body termed the *germinal spot* (Fig. 4, *f*). So that at this period the ovum resembles a nucleated cell having also a nucleolus. Graafian vesicles, though they may be seen before puberty in the ovary, after that period increase in number and in size, and may be observed in all stages of development scattered through the substance of the organ, those most advanced being near the surface. Towards the end of each menstrual period, such as are ripe burst, from the quantity of sanguinolent serum or blood which is poured into them from the external vascular membrane, and the ovum escapes from the surface into the fimbriated extremity of the Fallopian tube, which grasps the ovary by a reflex action in order to receive it, and through which it is conveyed to the uterus. The Fallopian tube is lined by ciliated epithelium, and the play of the cilia is directed towards the uterus—in the right Fallopian tube downwards from right to left, and in the left one downwards from left to right. The ovum, however, is conveyed to the uterus, principally by the peristaltic contractions of the muscular coat of the tube.

Corpora Lutea.—The cavity thus left in the ovary is most frequently filled with coagulated blood, the result of hæmorrhage from the vascular or external layer of the Graafian vesicle, which participates in the congestion occurring in all the pelvic organs during the menstrual period. This coagulum of blood becomes gradually absorbed, in the course of which it changes its colour, and assumes a yellow and puckered appearance. The cells of the membrane granulosa multiply and grow inwards upon the clot, and assist materially in filling up the cavity.* In this state it has been called *corpus luteum* (the yellow body), (Plate XVII. fig. 9, in which one large recent *corpus luteum* is seen in the centre of the figure, an older one on the right hand, and one still older on the left.) And it has been supposed to present such peculiar appearances when fecundation has occurred as to warrant medical men in asserting that pregnancy had taken place—a grave error, which modern science has completely exploded. These appearances are described as being,—1*st*, An irregular form in the false, but a regular one in the true *corpus luteum;* 2*d*, An absence of a central cavity lined by a membrane in the false, whilst in the true there are both; 3*d*,

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* Schrön and Gröhe, *ib.*

Absence of concentric radii in the false, while in the true they are present; *4th*, The false may be present in both ovaries, while the true only exist in one. All these signs have been shewn, by numerous observations, to be in no way distinctive. Thus, in women who have never had children, there have been found *corpora lutea* exactly resembling those supposed to follow pregnancy. In the lower animals, also, four or five *corpora lutea* have been found in the ovaries, resembling each other, although one fœtus only was found in the uterus. It must be manifest that these ideas were the result of the notion that fecundation took place in the ovary, which assuredly it never does. A *corpus luteum* occurring after a pregnancy, probably disappears less rapidly than in the unimpregnated condition, but such is the only possible difference which can exist in the two states. That it is possible for any physiologist or pathologist to pronounce with certainty between the bodies which do or do not coincide with pregnancy, has been demonstrated in the negative by several remarkable cases which have been raised in courts of law. The ovaries of females advanced in life are contracted, puckered, and indurated in consequence of the numerous cicatrices that this process has produced in their texture.

Puberty.—The capability for procreation marks a peculiar period of life, which has been called puberty, on account of the development the pubes then undergoes. In woman, this generally occurs between the thirteenth and sixteenth year, but is earlier in warm climates, and later in cold ones. It has also been observed to be earlier in manufacturing towns than in thinly-peopled districts. Mental and bodily habits exercise an influence; girls accustomed to luxury and indulgence undergoing this change earlier than those reared in hardihood and self-denial. At this time those general and local changes occur which distinguish the adult woman: the mammary glands enlarge; a deposition of fat takes place in the cellular tissue of the skin, which gives to the female form its roundness and fulness; and the menstrual fluid, the most unequivocal sign of puberty, commences to flow. In man, puberty is marked by the low and rough voice—from the enlargement of the larynx by the development of the thyroid cartilage to form the *Pomum Adami*, and consequent elongation of the vocal cords; by the growth of hair on the chin, upper lips, and cheeks, as well as over the body and limbs; the greater physical power and activity, as compared with the female; the capability of enduring more fatigue; and a larger amount of courage and daring. The capability of reproduction ceases in the woman, along with the function of menstruation, between the forty-fifth and fiftieth year; but in man the term is indefinite, and virile power may continue even in very old men.

FECUNDATION OF GERMS.

The germ-cells, prepared and formed in the ovaries, are discharged from those organs at each menstrual period, and would be excreted from the economy without being further developed, unless they encountered vibratile particles formed in another organ.

Fecundation in plants.—In phanerogamous plants, the pollen falls upon the stigma, which is usually covered with a viscid matter. Minute tubes grow from the pollen, and pass downwards through the loose tissue of the style, until they reach the ovule at its base. The tube then passes through the micropyle of the ovule, and reaches the embryonal sac, and the contact of the material in the pollen tube, with the embryonal or germinal cells constitutes the real act of fecundation. Of the nature of the stimulus so imparted, we know nothing; but the fact is well established in science that no ovule can furnish productive seeds unless the pollen has had access to it. Fecundation in many cryptogamous plants, is essentially of the same nature—the union of male and female elements produced by special organs.

Organs of fecundation in animals.—In all animals in which ova are formed the same union of male and female elements takes place. Two sets of organs analogous to those in plants are found. In some creatures, as in certain Mollusca, these are associated in one individual; but in all the vertebrate tribes they exist in different individuals, male and female. The former is furnished with organs called the *testes*, which secrete the spermatic or seminal fluid; the latter, with ovaries which have been already described (p. 374). The testes contain minute bodies, possessed of independent motion, which they retain for several days after they have been excreted. In them the fecundating power resides, for it is only when these come in contact with the ova discharged from the ovary of the female that the latter are ever developed into distinct living beings

From this moment that series of changes commences in the ovum whereby an embryo is formed. For this purpose, however, various circumstances are necessary, especially a fitting locality, proper temperature, moisture, &c. Seeds which have been impregnated retain the power of growth, or what some call dormant vitality, for many years; and when at length placed in favourable circumstances, they develop themselves. Generally speaking, instinct guides the lower tribes of animals to deposit their eggs in appropriate localities; and the extraordinary variety of such positions selected by insects, fishes, and reptiles, has furnished a curious subject of observation for the naturalist. In most birds, the fecundated ova are hatched by the mother, who elevates them to a proper temperature by the heat of her own body. In mammiferous animals, fecundated ova are retained in an organ—the uterus—which is provided for their reception, where they grow and become developed; and when at length they are capable of supporting an independent existence, they are excreted or parted from the body of the parent by the process of parturition.

Structure of the testes.—These organs are of an oval form, and consist of a body (Plate XVII. fig. 1, *a*, *i*, *b*,) and an elongated structure placed behind it called the *epididymis* (Fig. 1, *d*, *e*, *g*). The upper extremity of the epididymis is known as the *globus major* (Fig. 1, *d*), while the lower is the *globus minor* (Fig. 1, *g*). The gland has a tough fibrous tunic, the *tunica albuginea* (Fig. 1, *i*), which is projected inwards so as to form a prominence called the *corpus Highmorianum*, or *mediastinum testis* (Fig. 1, *c*, *f*). Numerous bands of connective tissue pass from the *corpus Highmorianum* to the capsule of the gland, thus dividing it into a number of compartments, in which lie the essential structure of the testicle, the *tubuli seminiferi*. These tubuli, originating by blind extremities at the surface of the gland, are at first much convoluted, but after passing inwards become straight, forming the *vasa recta* (Fig. 1, *b*, *s*). The *vasa recta* unite with each other in the substance of the *corpus Highmorianum*, and thus form a plexus called the *rete testis* (Fig. 1, *c*). A number of ducts, the *vasa efferentia* (Fig. 1, *d*), pass from the *rete testis*, and become convoluted, forming a series of cones, the apices of which are directed towards the *rete testis*. These cones are called the *coni vasculosi* (Fig. 1, *d*), and they constitute the chief portion of the *globus major* of the epididymis. The epididymis is formed by the windings of a duct or ducts derived from the *coni vasculosi*, and at length the duct issues from the vicinity of the *globus minor*, under the name of *vas deferens* (Fig. 1, *g*, *h*). This duct passes behind the bladder, uniting with the duct of the *vesiculæ seminales.* These vesiculæ are receptacles for the storing up of semen, where it is probably mixed with mucus. The duct formed by the confluence of the *vas deferens* with the duct of the *vesiculæ seminales* is called the *common ejaculatory duct*, and opens into the prostatic portion of the urethra in a small fossa or depression, the *sinus pocularis.* The testicle is thus essentially a tubular gland. The length of the tubular structure in man has been estimated (Lauth) at 1800 feet. The appearance of one of the tubuli seminiferi, seen under a high power, is represented in Plate XVII. fig. 2. It consists of a strong basement membrane lined with epithelium, and containing molecular matter, and large cells in which the spermatozoids are developed. At certain periods few of those large cells are seen, the tubuli containing chiefly molecular matter ; at other times they abound and contain one or more spermatozoids coiled up in their interior. (Plate XVII. fig. 3, *l*.)

Spermatozoids.—The form of the vibratile seminal particle varies in different animals. Various forms are shewn in Plate XVII. fig. 3 (see description of plate). In mammals generally, it has a round or oval extremity, a so-called *head*, and a filiform appendage called a *tail*, and varies in length from the 100th to the 500th of an inch (Plate XVII. fig 3, *a* to *g*). In birds, the thick extremity is more tapering, and the whole is of a spiral form (Fig. 3, *h* to *k*). In certain reptiles and fishes, the filament is much longer, and thickest in the middle, tapering at both extremities, having occasionally a delicate continuation wound spirally round the thicker portion (Fig. 3, *m* to *r*). In some insects and crustacea, they present curious irregular forms, without a filament, and are immoveable (Lower part of Fig. 3). In the vast majority of cases, however, they possess active contractile movements. In mammals especially, when watching these under the microscope, it is difficult to divest oneself of the idea that they are animalcules, as they progress through the fluid with the heads forward, propelled by continued vibratile lashings of the tail. The notion put forth by some observers, that they possess internal organs, we have never, after careful research, been able to confirm; and the circumstance that similar structures, with like movements, exist in the reproductive organs of many plants, negatives the idea of their being distinct animalcules. Hence, instead of *spermatozoa*, the term *spermatozoids* is more applicable to them.

Mode of fecundation.—The mode of fecundation varies in different animals. In some molluscous tribes, and in most plants, male and female organs are united in the same individual. Such an animal or plant is an *hermaphrodite*, and is usually self-impregnated. In fishes, the female sheds its spawn, and the male, swimming over it, sprinkles the spermatic fluid on the ova, and at certain seasons may be observed to follow her for that purpose. In the higher animals, union of the sexes takes place for the same end. In reptiles, especially in the frog and toad, the male clings to the back of the female, and sheds the semen over the ova immediately after they have left the cloaca. In birds and mammals, it is necessary that the spermatic fluid be deposited in the body of the female by the intromission of the male organ. From the circumstance that fecundation may take place in fishes and reptiles, as in plants, by simply sprinkling the male element over the female ova, has originated the modern practice of artificial impregnation. In the same way that horticulturists can multiply varieties, and even fertilise plants with pollen received from a distance; so, by sprinkling the fluid from the milts of male fishes over the innumerable ova which may be squeezed from the roe of the female, they may be fecundated, preserved, and reared in artificial ponds. At this moment, many of the rivers and lakes of France, Scotland, and Australia are being stored with large accessions of valuable fish so raised, in order to increase the amount of food for the people.

For a long time it was supposed that the mere contact of the vibratile spermatozoids with the ova was all that was necessary to produce fecundation; but it was first shewn by Martin Barry, and has been subsequently confirmed by many other physiologists, *that the spermatozoid actually finds its way into the ovum by a minute aperture*, so that the male and female elements ultimately blend or melt into one another. (See description of the development of the *Ascaris Mystax*, p. 48.) This fact may now be considered well established, and serves to explain many circumstances long known as to the resemblances which exist in feature and in qualities, mental and bodily, between parents and their offspring. Thus it has long been a matter of popular observation, that the child, in all that relates to the outward form, the gait and manners, takes after the father; while as regards the size, internal qualities and dispositions, the mother predominates. Not, however, that the male is wholly without influence on the internal organs and vital functions, or the female wholly without influence on the external organs and locomotive powers of their offspring. The law is only general, although it holds very extensively among cattle, as shewn by Mr Orton and Dr A. Harvey. Such facts seem in their turn to be accounted for by the circumstance that the spermatozoid enters and melts down in the external parts of the yolk of the egg,—that is, in connection with those layers of the germinal membrane which, as we shall subsequently see, form the nervous system and muscles; whereas the glands and internal organs are formed from the mucous layer, which is that part of the membrane furthest removed from the action of the male element.

CHANGES IN THE OVUM WHICH FOLLOW FECUNDATION.

We have seen that ova are formed and discharged from the ovary at regular intervals by the adult female, but that it is only when the spermatozoid enters them that fecundation is produced. At that period the ovum presents the characters of a nucleated cell,—the *zona pellucida* being the cell-wall; the *germinal vesicle* being the nucleus; the *germinal spot* the nucleolus; while the fluid between them is opaque and granular, and called the *vitellus*, or yolk (Plate XVII. figs. 4 and 13). The size and relative amount of these three parts of each ovum vary in different animals, but they are present in all. If fecundation does not take place, the ovum degenerates, breaks down, and is ultimately excreted in the mucous discharge from the external passages. But if it encounter the spermatozoids, and one or more penetrate it, then those changes commence which terminate in the formation of an embryo. (See Plate XVII. figs. 14, 15, 18, 19, and 20, representing ova with spermatozoids in the interior.) These changes have now been followed in numerous animals, and the principal efforts of zoologists are at present directed to the elucidation of the transformations which take place at an early period in living beings; so that the whole subject is not only very extensive, but is constantly acquiring new facts. The study of human embryology is incomplete, for, although an ovum has been twice discovered after death in the Fallopian tube of woman (Letheby),* it has never been seen at that period when it enters the uterus. In the dog, rabbit, sheep, and other mammals, however, the various transformations have been very carefully described; and, as it is certain that the same essential mode of development occurs in them as in man, the changes observed in the dog, according to Bischoff, will be selected as a type of what takes place in the impregnated ovum of the higher animals. (Plate XVII. figs. 12–24, and Plate XVIII.)

When the ovum leaves the Graafian vesicle, there is adherent to it externally a greater or less number of the cells which form the granular membrane. On removing these artificially, the ovum presents the appearance figured in Plate XVII. fig. 12, when magnified fifty diameters linear. It is composed of a dark, opaque yolk, surrounded by the *zona pellucida*, or vitelline membrane. On cracking this ovum between two glasses, or on tearing it with a needle, the granular yolk flows out, and the germinal vesicle escapes, as in Fig. 13, *a*. If such an ovum encounter spermatozoids, the changes subsequently represented take place. One or more enter the ovum, when they and the germinal vesicle are dissolved in the yolk,—a circumstance to which the whole structure is indebted for its continuance and for its power of, as well as direction in, development.

Development of the Embryo.

The first change observable after fecundation is that the granular yolk begins to separate into two parts,—a process accomplished by the spontaneous aggregation of the molecules of which it is composed into two masses instead of one. (See page 39 and fig. 14.) Each of these two subdivide, producing four (Fig. 15); each of these into other two (Fig. 18); and so on, until at length the whole is reduced into a mass of molecular corpuscles (Figs. 19 and 20), having a clear space or nucleus in their centres, and subsequently distinct cell-walls (Fig. 21). These corpuscles next arrange themselves in a layer externally, immediately lining the *zona pellucida*, so as to form a membrane, which is called the *germinal membrane* (Fig. 17). At one part of this, it will be observed that the cells collect in larger numbers, and are closely packed together, forming the *germinal area*, where the embryo first appears. The ovum has now entered the uterus, and its appearance at this period, magnified ten times, is represented in Fig. 16. By cutting or tearing out the portion of the germinal membrane which contains the germinal area, and magnifying it, the subsequent changes it undergoes can be well studied. The germinal area now enlarges ; at first round (Fig. 22), it becomes oval (Fig. 23), and then there appears in it a clear space,—the *area pellucida* (Fig. 24, *c*). At the same time, the germinal membrane becomes thicker, and is now divisible into two layers,—an upper or outer, called the *serous* or *animal*, from which the epidermis and cerebro-spinal system are developed ; and an under or internal, called the *mucous* or *vegetative layer*, which ultimately forms the epithelium of the alimentary canal and its appendages.

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* Philosophical Transactions. 1858.

The future changes in the embryo may be observed by watching the changes in these two layers, and of another that afterwards forms between them in the germinal area, called the intermediate or *vascular layer*, from which are developed all the structures between the epidermis, on the one hand, and the epithelium of the alimentary canal and appendages, on the other. In the centre of the enlarged germinal area there now forms a groove or channel, the *primitive groove*, by an elevation on each side of the serous layer of the germinal membrane (Fig. 24, *c*). This groove enlarges anteriorly, and tapers to a point posteriorly (Plate XVIII. fig. 1), and ultimately becomes closed, by its sides,—*laminæ dorsales*,—passing over it and uniting, so as to form a tube. In the floor of this tube, the embryo brain and spinal cord are differentiated in a way to be afterwards described. This tube is the cerebro-spinal canal. Underneath the canal there appears at a very early period a dense substance called the *chorda dorsalis*, a structure represented in the adult chiefly by the intervertebral discs. From the *chorda dorsalis*, as from a centre, two laminæ pass upwards,—the *dorsal laminæ*, already referred to ; while two, the *ventral laminæ*, pass downwards, and meeting below, complete the body of the embryo (Figs. 1, 3, and 4). A linear mass of square-shaped cells forms on each side of the *chorda dorsalis*, the so-called *primitive vertebræ*, from which are formed the vertebral column and certain other parts (Plate XVIII. figs. 3 and 4).

The embryo is now raised prominently upwards above the serous layer (Fig. 2, which shews a lateral view of the embryo), and between it and the mucous layer another mass of cells is formed which constitutes the third or *vascular layer*, above described. Here blood-vessels are developed from large triangular cells, so as to form a plexus (Plate XVIII. figs. 3 and 4) which unites with the embryo heart and aorta (Figs. 5 and 6). Thus a circulation is established, extending over the entire ovum, with the exception of its two poles (Fig. 7). The embryo is now raised still further above the surface of the germinal membrane, while the duplications and re-duplications of its three layers, which are constantly receiving thickness by cell growth, gradually produce the various organs and textures of the body. Three vesicles or sacs are formed in connection with these layers,—the *amnios*, or amnion (from ἀμνός, a sheep, because first observed in that animal), with the serous ; the *allantois* (ἀλλάς, αλλᾶντος, a sausage ; εἶδος, shape) with the vascular ; and the *umbilical* (*umbilicus*, the navel) with the mucous layer.

The upper or serous layer of the germinal membrane may be observed from an early period to be reflected backwards, from before backwards, and laterally, so as gradually to inclose the embryo in a sac (Figs. 3 and 5). This reflexion is at first double, but after it closes over the back of the embryo, the two layers separate from each other, the outer passing outwards to be incorporated with the *zona pellucida*, while the inner forms a sac, in which the embryo is suspended. (Fig. 7). It is the *amnios* or *amniotic sac.* From the lower portion of the abdominal groove, and at the inferior extremity of the embryo, a swelling may now be observed (Figs. 10, 11, *bb*). This rapidly enlarges, and, at first open in the middle (Fig. 12, *a*), coalesces to form another sac, which hangs out of the lower portion of the abdominal opening. It is the *allantois,* a sac communicating posteriorly with the alimentary canal and the ducts of the Wolffian bodies or primitive kidneys, the ureters, Fallopian tubes and *vasa deferentia.* This sac is seen at the lower part of fig. 10. About the same time the middle layer of the germinal membrane, the vascular, splits into two layers, the inner one of which, coalescing with the mucous layer, forms the alimentary canal, while the outer is differentiated so as to form the muscles of the trunk and abdomen. The space left by the divergence of these layers of the vascular membrane is represented in the adult by the pleuro-peritoneal cavity. As the ventral laminæ, already described, meet in the middle line of the abdomen, part of the inferior or mucous layer becomes more or less constricted by the closure of the laminæ so as to form a third sac or vesicle called the *umbilical sac.* This sac is therefore the portion of the mucous layer left outside the body of the embryo—the portion within the cavity of the embryo becoming the alimentary canal. The outer (umbilical sac) is connected with the internal part by a pedicle or duct. The mode of formation and relation of these three sacs will be better understood from the diagram seen in Plate XVIII. fig. 9, in which *a* is the back of the embryo; *b* the amnios; *c* the umbilical vesicle connected with the embryo by a pedicle, *d;* and *e* is the allantois growing backwards and downwards, and continuous with the vascular layer by a pedicle *f.*

The functions of these sacs may be briefly stated to be as follows. The umbilical vesicle, containing part of the yolk, is for the nourishment of the early fœtus. The allantois brings the blood of the fœtus into relation with the surrounding media for the purposes of nutrition and respiration. It is seldom of large size in mammalia, because it is soon supplanted by another organ, *the placenta,* into the structure of which it enters. The amnios secretes a fluid, termed amniotic fluid, in which the fœtus floats, and by its reflexions it permits the *allantois* to pass outwards so as to contribute to the formation of the placenta.

Development of the Chorion.—While the ovum is very small, its outer surface becomes shaggy from the appearance of numerous villi. These villi, at first simple, soon become branched by lateral processes passing from them (Plate XVIII. fig. 11). This villous covering is the *chorion.*

*Development of Special Organs in the Embryo.**

Development of the skeleton.—Immediately below the primitive cerebro-spinal canal there appears in the middle or vascular layer, a structure termed the *chorda dorsalis,* or notochord, consisting of large cells, surrounded by a thin sheath. About the same time, small square-shaped masses are to be seen on each side of the *chorda dorsalis* (Plate XVIII. figs. 1, 2). These are the *primordial vertebræ,* and each pair is ultimately developed by differentiation into the osseous and cartilaginous portions of a permanent vertebræ, the head of a rib, the central parts of a spinal system of nerves, and the cutaneous and muscular parts covering the back.* During this process of development, the *chorda dorsalis* becomes constricted, and ultimately portions of it form the centres of the bodies of the permanent vertebræ, while other portions are persistent in the intervertebral disks. Thus the vertebral column is formed.

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* For further details reference is made to works specially devoted to the subject. See also description of Plates XVII. and XVIII.

Development of the skull.—At a very early period of fœtal life, two curvatures are to be observed near the anterior extremity of the embryo, one at the point corresponding to the junction of the vertebral column with the skull, and the other opposite to the second cerebral vesicle. Behind the latter curvature, the dorsal plates bend downwards and unite inferiorly, so as to form four arches, behind each of which there is a cleft or fissure, termed a *branchial cleft* (Plate XVIII. fig. 14, *d*, *f*). The posterior part of the first cleft remains open in the fully developed fœtus as the external aperture of the ear, the cavity of the tympanum, and the Eustachian tube, while its anterior part, along with all the other clefts, are ultimately obliterated. We have now to consider, first, the development of the cranium, and second, that of the face.

1. *The cranium.*—The *chorda dorsalis* terminates at the posterior part of the *sella turcica*, the fossa in the base of the skull for the reception of the pituitary body. In front of this point, two thick bars of cartilage, separated by a thinner portion between them, pass forwards, and unite in front of the ethmoidal region. These have been termed the *lateral trabeculæ* of Rathke. The whole of the base of the skull is now cartilaginous, while the vault of the cranium is membranous. The cartilaginous portion ossifies and differentiates into the occipital bone below its protuberance, the petrous and mastoid portions of the temporal, the sphenoid and ethmoid; while the membranous portion becomes the parietal, frontal, upper part of the occipital, and the squamous portion of the temporal. The vomer and perpendicular plate of the ethmoid are developed from a vertical process of cartilage passing forward from the neighbourhood of

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* Quain's "Elements of Anatomy," 1867, p. 16; Goodsir's "Anatomical Memoirs. On the Morphological Constitution of the Skeleton of the Vertebrate Head," vol. ii., p. 89, *et seq.*

the termination of the chorda dorsalis, called the *ethmo-vomerine* cartilage.*

2. *The face.*—The bones of the face are all originally cartilaginous, and are developed as follows: A process passes from the upper or first visceral arch forwards beneath the eye, and forms the sides of the face, namely, the superior maxillary and malar bone (Plate XVIII. fig. 14, *c*). Coincident with the development of the two processes just described, another process, called the *middle frontal process*, passes down from the anterior extremity of the ethmo-vomerine cartilage between them, and becomes the nose and middle part of the upper lip. The lower part of this process bears the upper incisor teeth. In man it is blended, even at a very early period of fœtal existence, with the *superior maxillary* process; but in all other mammals it remains separate as the *intermaxillary* or *premaxillary* bones. In the three upper visceral arches, narrow strips of cartilaginous tissue make their appearance. These are the subjects of remarkable changes. The first, or upper piece, is divided into three parts: the proximal, or that in connection with the *basis cranii*, is developed into the palate plate and internal pterygoid process of the sphenoid bone; the second forms the incus and its two processes; while the remaining part, long and narrow, passes downwards and forwards so as to unite with its fellow of the opposite side, and is called *Meckel's cartilage.* The upper part of this cartilage forms the malleus and its handle, and the lower part forms a rod, on the external surface of which the lower jaw is developed. It ultimately disappears, except a small portion, which is represented by the *processus gracilis* of the malleus. The proximal extremity of the firm tissue in the second arch forms the stapes, and the distal extremity the styloid process of the temporal, the stylo-hyoid ligament, and the small cornua of the hyoid bone. A portion of that of the third arch forms the great cornua and body of the hyoid bone. Thus are formed the bones of the face and ear.

Development of the limbs.—The upper and lower limbs are developed from the ventral plates on the sides of the body. The upper limb appears before the lower, and according to Kölliker, the division into arm and fore arm, thigh and leg, occurs about the eighth week. About the same time the division into fingers and toes also takes place (Plate XVIII. figs. 10, 13, 15).

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* Quain's "Elements of Anatomy," 1867, p. 65.

Development of the organs of circulation.—The heart is at first a mass of cells, shewing rythmical contractions even before muscular tissue is developed, but at an early period it is a simple dilated tube having two veins entering its posterior end and a large arterial trunk passing from its anterior. The tube soon becomes constricted in two places, so as to form three compartments, the posterior of which is the auricular portion, the middle the ventricular, and the anterior the *bulbus arteriosus.* Septæ next make their appearance in these compartments, so as to divide the auricular portion into the two auricles, the ventricular into the two ventricles, and the bulbus portion into the aorta and pulmonary artery. The heart also becomes twisted upon itself somewhat like the letter S, and this process goes on until the two auricles are anterior, at the base of the heart, the two ventricles posterior, forming the cone. From these originate the pulmonary artery and the aorta (Plate XVIII. figs. 3 and 6). The bulbus arteriosus is at first a tube which, after passing forwards a short distance, splits into two. These diverge, but afterwards unite to form a large tube running down behind the heart in front of the vertebral column. This tube is the descending aorta. Thus two arches are formed. Four other pairs of arches are also developed, each arch being placed in one of the branchial processes already described (fig. 14). These arches never co-exist, as the highest disappear before the lower are developed. This transitory arrangement of blood-vessels resembles somewhat the branchial arteries in fishes; but it soon disappears. Embryologists have not satisfactorily traced the development of these vascular arches into permanent structures. According to some, the fifth or uppermost arch remains persistent as the anastomosis between the internal carotid and vertebral arteries through the circle of the Willis at the base of the brain; the fourth, as the inosculation between the superior thyroids of the external carotids and the inferior thyroids of the subclavian; the third, as the subclavian arteries; the second becomes, on the left side, the arch of the aorta, while that on the right side disappears; and the first is represented in the fœtus by the *ductus arteriosus* on the left side, the right having disappeared at an earlier period.*

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* For further details regarding the development of the great arteries and veins,

Development of the nervous system. — The spinal cord and encephalon are developed in a deposit of blastema in the bottom of the primitive groove. As this groove is formed by the serous layer of the embryo, it follows that the cerebro-spinal system is developed from this layer. The layer of blastema, composed at first of cells uniform in size and appearance, increases in thickness in each lateral half so as to form a furrow or groove, the sides of which growing upwards and uniting produce a tube or cylinder, which is represented in the mature condition by the ventricles of the brain and the cerebral canal of the spinal cord. According to Remak and Kölliker, the posterior roots of the spinal nerves, with their ganglia, are separately developed and grow inwards towards the cord, while the anterior pass outwards from the cord. The nerves are developed from differentiated masses of blastema, and grow inwards till they reach the cord. Thus we have formed the spinal cord, with the various motor and sensory nerves ramifying through the body. With regard to the development of the *brain*, it is first to be noted that it is really a portion of the nervous tube just described, modified into various ganglionic masses. There is at first no enlargement representing brain, a condition which is persistent in the *Amphioxus lanceolatus.*[*] Soon, however, the anterior part of the medullary tube enlarges, and becomes constricted into three parts, so as to form three vesicles, called the *primary cerebral vesicles* (Plate XVIII. figs. 4, 5, 6, and fig. 8, *a*, *b*, *c*, *d*). These three vesicles are at first in a straight line ; but three bends make their appearance : the most posterior, at the junction of the posterior vesicle with the spinal cord ; the next between that part of the third vesicle forming the medulla and that developed into cerebellum ; and the anterior appears in the middle vesicle between the parts from which are developed the optic thalami and corpora quadrigemena. The anterior is now placed nearly at a right angle with the middle vesicle. The following changes next occur in these three vesicles. Beginning with the posterior primary vesicle, we find that its floor is developed into the medulla oblongata (a continuation of the cord). The posterior part of its roof is never closed by nervous matter, having only membrane over it, and this open part is

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reference is made to Kölliker, "Entwicklungsgeschichte," p. 412, *et seq.* Quain, vol. i. pp. 325 and 483, &c.

[*] Goodsir's "Anatomical Memoirs," vol. i. p. 378.

represented in the adult by the floor of the fourth ventricle, communicating below with the canal of the spinal cord. The anterior part of the roof is differentiated into the cerebellum, and the transverse commissural fibres of the cerebellum constitute the *pons Varolii.* The *vermiform process* of the cerebellum appears before the two lateral hemispheres. In the floor of the middle or second cerebral vesicle, matter is deposited so as to form the *crura cerebri*, and in the roof we have developed the *corpora quadrigemena*, an antero-posterior median groove being first seen about the sixth month, and a transverse, separating the *testes* from the *nates*, first making its appearance about the seventh month of intra-uterine life. The primitive cavity of the second cerebral vesicle remains persistent as the Sylvian aqueduct, or *iter a tertio ad quartum ventriculum.* The development of the anterior primary cerebral vesicle is more complicated. At a very early period, two vesicles are developed from the anterior primary vesicle, one on each side. These vesicles have been termed the *hemisphere vesicles*, because from them are developed the hemispheres—the *corpora striata* appearing in the floor, while the hemispheres, properly so called, constitute the roof. The external surface of the mass termed *corpora striata* is the *Island of Reil*, seen in the Sylvian fissure. The cavity of these vesicles is represented by the lateral ventricles, and between the double partition separating them, we have the fifth ventricle. The cavity of the anterior primary vesicle, behind the cerebral vesicles, forms the third ventricle, the floor being formed by the *optic thalami* which are at first hollow, while the roof is formed by the *velum interpositum*, a layer of *pia mater*, which is folded into the brain through the transverse fissure. As development proceeds, the communication between the cavity of the anterior cerebral vesicle (third ventricle) and those of the hemisphere vesicles (lateral ventricles) becomes smaller and smaller, and ultimately constitutes the *foramen of Munro.* The margin of this foramen forms anteriorly the *fornix*, an antero-posterior commissural set of fibres, and posteriorly the *corpus fimbriatum* and *hippocampus major*, and as the hemispheres increase in size they grow backwards, so as to overlap the *optic thalami, corpora quadrigemena*, and cerebellum. The great transverse commissural mass, *corpus callosum*, is first seen about the end of the third month. The first trace of convolutions is seen about the fourth month. They are at first indistinct, and continue so till the seventh month, after which they are rapidly developed. The Sylvian fissure appears at the fourth month, and is soon followed by the fissure of Rolando. Such is an outline of the development of the brain.

Development of the eye.—The eye first appears as a hollow process in connection with the anterior cerebral vesicle (Plate XVIII. fig. 5, where the first cerebral vesicle is expanded laterally; fig. 6; fig. 8, *c*; and fig. 13, *b*). This process soon becomes a round vesicle (*primary optic vesicle*) connected posteriorly with the anterior cerebral vesicle by a hollow pedicle. The optic vesicle now approaches the cuticle and becomes invaginated, carrying a portion of the cuticle along with it. This invaginated portion of cuticle, at first a pouch, becomes constricted to form a sac, and is ultimately severed from its connection with the general cuticle, thus forming the *lens*. The primary optic vesicle now undergoes a second invagination behind the lens until the opposite surfaces come into contact, and the cavity of the primary optic vesicle disappears. According to Kölliker, the invaginated portion forms the retina and the layer of hexagonal pigment cells in the choroid; and the outer portion, the pigmentary (branching pigment cells) and probably the vascular part of the choroid. The cup-shaped cavity behind the lens, called the *secondary optic vesicle*, is soon filled with the vitreous humour. The iris is developed about the second month as a septum projecting from the anterior part of the choroid. The sclerotic and cornea are formed from tissue external to the eye. The lens in the fœtus is surrounded by a vascular tunic, the fore part of which is persistent in the young of many animals for several days after birth. It is then termed the *pupillary membrane*. In the human being it is atrophied before birth. The eyelids are folds of integument. The lachrymal canal is the representative of the fissure between the frontal process and the maxillary lobe of the embryo.*

Development of the ear.—The ear is developed from a vesicle, the *primary auditory vesicle*, above and behind the second branchial arch (Plate XVIII. fig. 5, where the embryo ears are seen opposite the third cerebral vesicle; fig. 8, *f*). This vesicle, however, is not a process from the brain, as is the case in the eye, but an invagination of the cuticle. The first part developed is the membranous labrynth, afterwards the semicircular canals, and finally the cochlea. The osseous labrynth is developed from cartilage, continuous with the cartilage at the base of the primordial cranium. The stages of development of the intricate portions of the cochlea have not yet been clearly made out. The development of the middle and external ear have been already described. The external meatus, tympanum, and Eustachian tube are the remains of the upper part of the first branchial cleft ; the incus and malleus are formed from the upper part of Meckel's cartilage (part of the first branchial arch), while the stapes is derived from the cartilage of the second branchial arch.

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* Quain, vol. ii. p. 737-9.

Development of the nose.—The nose is a development of the integument (Plate XVIII. fig. 13, *a*). The olfactory bulbs, at first hollow, are processes from the two vesicles which ultimately form the cerebral hemispheres (p. 394). It has not yet been made out whether the olfactory nerves grow from the bulbs, or originate, like other nerves, from separate masses of blastema. The nostrils first appear as two grooves separated by the frontal process. They are shut off from the eye by the lateral frontal process, and the side wall of the nostril is completed by the maxillary processes. The nostrils at this period communicate with the mouth. The palate is now developed by transverse growths towards the middle line, and ultimately they unite. Sometimes we have, by their non-union, the congenital deficiency known as cleft-palate.

Development of the alimentary canal.—The alimentary canal first appears as a groove directed towards the yolk. The groove is lined by the mucous layer of the embryo, which ultimately forms, as already mentioned (p. 384), the epithelium of the canal. The wall of the groove is formed by the deeper division of the intermediate or vascular layer of the embryo. The groove soon closes, so as to form a long, straight tube, stretching in front of the vertebral column from the base of the skull to near the posterior extremity of the embryo (Plate XVIII. fig. 13, *m*, and fig. 15, *l*). This tube, however, communicates with the yolk-sac, or umbilical vesicle, by an opening on the ventral aspect, which speedily becomes a narrow duct, named the *omphalo-enteric duct* (Fig. 9, *d ;* fig. 15, *m*). This duct soon disappears. The intestine now forms a curve or loop in the centre of the body, and a portion dilates to become the stomach (Fig. 13, *e*, and fig. 15, *k*). The stomach is at first vertical, turns over on its right side, so that the right lateral surface becomes its posterior surface. This explains the anatomical fact of the right pneumogastric supplying the posterior aspect of the stomach, while the left supplies its anterior aspect. The great intestine, at first narrower than the small, in the early embryo shews no cæcum. The mouth is developed by an infolding of the integument above the highest branchial arch, and is separated at first from the pharynx by a partition. The anus and lower part of the rectum are also invaginations of the outer surface. It is remarkable that villous processes are at first found throughout the whole alimentary canal, but ultimately disappear in the stomach and large intestine. Occasionally, diverticula are found in the adult in connection with the lower part of the ileum. These are believed to be remains or developments of the original omphalo-enteric duct. Umbilical hernia arises from the want of complete apposition of the wall of the abdomen at the umbilicus.

Development of the liver.—The liver appears as two cul-de-sacs or tubes, arising from the intestinal canal immediately beneath the dilation for the stomach (Plate XVIII. fig. 13, *k*, and fig. 15, *i*, *i*, *i*). These processes, according to Remak, consist both of the epithelial and muscular parts of the intestine. They increase in size by the development of glandular substance, and surround the *omphalo-mesteric vein*, the vein bringing blood from the umbilical vesicle, and from the wall of the primitive alimentary canal (Figs. 6 and 7). As the umbilical vesicle decreases in size, the omphalic portion of the vein also decreases, and the mesenteric portion coming from the alimentary canal becomes the *portal vein*. The continuation of the omphalo-mesenteric vein passing from the liver to the general circulation receives the name of the *hepatic vein*. At this period, then, the liver is supplied with blood chiefly by the portal vein. Coincidently with these changes, the allantois is being developed so as to form, along with the decidual membranes, the placenta; and as the placenta increases in size, a time arrives when the liver receives more blood by the *umbilical vein*, or vein coming from the placenta, than from the portal vein.* The umbilical vein, on reaching the liver, divides into two branches; one of these, the smaller, passes onwards to the *vena cava inferior*, and is called the *ductus venosus;* the other joins the *vena portæ.*

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* Dalton's Physiology, p. 664.

Several other small branches are given off by the umbilical vein to the liver. After respiration is established, and blood ceases to come by the umbilical vein, it and the *ductus venosus* contract and shrivel up, the umbilical vein constituting the round ligament of the liver, while the *ductus venosus* disappears. (See pp. 224, 225, and Plate XI. fig. 16, and description.)

Development of the salivary glands, and pancreas.—These organs are developed as simple canals with small processes passing them. In the case of the salivary glands, these canals communicate with the mouth, while that of the pancreas arises from the left side of the intestine, close to the spleen.

Development of the organs of respiration and organ of voice.—The lungs are at first diverticula from the œsophageal portion of the alimentary canal, and their internal cavities are lined by a prolongation of the lining of the œsophagus. At a later period, they are connected with the digestive tube by a pedicle which becomes the trachea (Plate XVIII. fig. 15, *a*). The lungs are seen at a very early period of development, and the air cells are rapidly developed round the extremities of the ramified bronchial tubes. Until birth, the lungs are of small size, and occupy a small space at the back of the thorax. On respiration being established, they expand so as to fill the cavity. The rudimentary larynx appears as two slight enlargements separated by a fissure, and embracing the communication between the pharynx and trachea. According to Rathke, all the true cartilages are formed at the same time. The larynx is small in childhood. In the female, the larynx retains its comparatively small size, and rounded thryroid cartilage anteriorly ; but in the male the cartilages become stronger, and the alæ of the thyroid cartilage project forwards so as to form the *pomum Adami.* The vocal cords are thus lengthened. The cartilages undergo partial ossification from middle life to old age.

Development of the blood glands.—The *spleen* appears about the seventh week, close to the pancreas, but by the tenth week it is placed at the great end of the stomach. It is developed in a special mass of blastema. Kölliker has observed the *thyroid gland* at the end of the third month, as consisting of shut sacs with cells in their interior. This organ is relatively larger in the fœtus than in after life. The *thymus gland* (Plate XVIII. fig. 15, *b*) has been seen by Simon in embryoes of swine and oxen about half an inch in length, as a simple tube. From this tube lateral diverticula arise containing corpuscles. By the twelfth week, the thymus consists of lobules ; it rapidly increases in size during fœtal life, and continues to grow after birth to the end of the second year. By the tenth or twelfth year it becomes a fatty mass, and at puberty it has almost disappeared. The *supra renal capsules* originate from blastema different from that of the kidneys. Some observers (Goodsir) have seen at an early period these organs apparently in one mass, others in two separate masses united together, while many have seen them at birth completely separated from each other. At one period, about the fifth or sixth week, the supra-renal capsules are larger than the kidneys, but ultimately they become much smaller. Nothing whatever is known definitely of the development of the lymphatic glands, Peyer's glands, pituitary body, or pineal gland.

Development of the urinary and generative organs.—At a very early period in the development of the human embryo, two ridges of blastema appear, one on each side of the primitive straight alimentary canal. These increase in size,—vesicles, and afterwards tortuous cæcal tubes, are developed in them, communicating with a duct which runs along the outer side of each organ. These are the *primordial kidneys* or *Wolffian bodies*, named after their discoverer, C. F. Wolff (Plate XVIII. fig. 13, *o* ; fig. 15, *o*). The ducts open into the allantois, and a whitish excretion, containing uric acid, has been found in them and in the allantois. As development progresses these bodies decrease in size, and ultimately almost entirely disappear, their ducts, however, becoming modified into certain permanent structures, as will be afterwards described.

The *kidneys* are not developed from the Wolffian bodies, but from separate masses of blastema behind their upper end. At first smooth, the kidneys soon become lobulated, each lobule consisting of a number of cæcal tubes which are modified into the *tubuli uriniferi*. The *Malpighian bodies* have been seen at a very early period. The *ureters* are believed by Rathke to commence separately from the kidneys, and afterward to become united to them. The ureters open into the allantoid sac. The lower part of the allantois is retained in the abdomen by the closure of the ventral walls at the umbilicus, and receives the ducts of the Wolffian bodies and of the ureters. This portion becomes dilated, and afterwards constitutes the *urinary bladder* (Fig. 9, *f*). The contracted part above this dilated portion, passing from the bladder to the umbilicus, is afterwards known as the *urachus.* The bladder at first communicates freely with the lower end of the alimentary tube. This general cavity is called the *cloaca*, and represents the permanent condition in birds and reptiles. Soon, however, a partition is developed, dividing the cloaca into two parts, the posterior constituting the *rectum*, opening externally by the anus, while the anterior has been termed the *sinus urogenitalis*, and receives the ducts of the Wolffian bodies as well as those of the kidneys and of the ovaries or testes.

The *generative organs* are developed from separate masses of blastema on the inner aspect of the Wolffian bodies. It cannot at first be determined whether male or female organs are to be the result of the development. The Wolffian bodies are pushed outwards by the development of the kidneys above and between them, and they gradually decrease in size. A white elongated thread-like mass of blastema is seen on the front of each Wolffian body, running along the duct. This becomes a tube termed the *Müllerian duct.* The Müllerian ducts become fused together at their lower end, and, along with the ducts of the Wolffian body, form a single cord—the *genital cord.* Now commences a distinct differentiation between the organs of the sexes. In the female, the portion of the Müllerian ducts united together is developed into the *vagina*, *cervix*, and lower part of the *body* of the *uterus.* This partial formation of the uterus by the union of two ducts explains the occurrence occasionally of a double or horned uterus. The upper part of the body of the *uterus* and the *Fallopian tubes* are formed by the remaining upper portions of the Müllerian ducts. A very different development occurs in the male. Here the Müllerian ducts undergo little development, and are represented in the adult by the *vesicula prostatica*, *sinus pocularis*, or *utricle*, first described by Morgagni, and situated in the floor of the prostatic portion of the urethra, and in front of the *caput gallinaginis*, or *verumontanum.* This little recess, therefore, represents in the male a portion of the uterus and the vagina in the female. The united portions of Müller's ducts disappear. The male organs of generation are developed partly from the mass of blastema already referred to, and partly from the ducts of the Wolffian bodies. The ducts of the latter form the *vasa deferentia* and *ejaculatory ducts*, the *vesiculæ seminales* being cul-de-sacs from their lower part. Part of the duct of the

Wolffian body becomes the *epididymis*. According to Cleland and Banks the *coni vasculosi* are developed from separate deposits of blastema. The testicles are, until the seventh month, in the abdominal cavity. They then descend through the internal inguinal ring into the scrotum pushing a pouch of peritoneum before them. This pouch becomes constricted, and is ultimately cut off from the abdominal portion of the peritoneum, so as to form the *tunica vaginalis*. The external organs of generation are first represented by a small body projecting from the median line in front of the cloacal opening, having a groove on its under surface. This body is the rudimentary organ which becomes the *clitoris* in the female and the *penis* in the male. About the eleventh or twelfth week, a transverse band divides the anal from the genito-urinary passage. Two cutaneous folds, one on each side of the clitoris, become, in the female, the *labia majora*. In the male, the penis enlarges, and the margins of the groove on its under surface unite so as to form the *urethra*. The lateral cutaneous folds already mentioned unite so as to form the scrotum. When the union of the urethra canal is not complete, and the penis is small, we have then the condition of hypospadias.

In the human ovum similar changes occur to those in the dog. The early stages, indeed, may be said to be identical. The umbilical vesicle and allantois, however, never become so large, and according to a dissection of a fœtus by Müller, supposed to be twenty-eight days old, union between the two may be observed even at that early period. The amnion is formed in the same manner as in the dog, very early, and continues during the whole period of intra-uterine life, constituting the membrane that surrounds the fœtus. On the chorion, the villi become concentrated on a particular spot, while the rest of its surface becomes smooth. The allantois grows into this part of the chorion, and blends with it, as will be afterwards more particularly described. About the beginning of the second month, the umbilical vesicle begins to disappear, it shrinks together, its peduncle uniting with that of the allantois to constitute the umbilical cord. Its remains may sometimes be traced in the fœtal coverings at birth. All the organs are now evolved, and are gradually perfected during the remainder of intra-uterine life.

In birds. — The same process previously described occurs essentially in the egg of the bird. In the bird there is no uterus. The ovum is maturated out of the body of the animal. In the ovary of the common fowl, numerous eggs may be seen in various stages of development. When discharged from the ovary into the Fallopian tube or *oviduct*, the egg consists of a large globular yellowish yolk inclosed in a transparent vitelline membrane. At one spot on the surface of the vitellus, there is a round white spot, the "*cicatricula*," in the centre of which is the germinal vesicle. The peristaltic actions of the muscular wall of the oviduct forces the egg downwards, and during its passage a homogenous layer of a gelatinous deposit is formed around the vitelline membrane. This is termed the "*chalaziferous membrane.* The egg is still pushed downwards with a slow rotatory motion, and the chalaziferous membrane is twisted in opposite directions so as to give rise to two fine cords, running from the opposite poles of the egg, termed the "*chalazæ;*" and from the mucous membrane of the oviduct there exudes an albuminous substance, the so-called albumin, or "*white of egg*." In the next part of the oviduct, another material is deposited outside the albumin, in the form of three distinct membranes, layers, or envelopes ; and in the lower part of the oviduct, which is wider than the rest of the canal, the villous mucous membrane transudes a fluid containing a large amount of calcareous salts, which are deposited amongst the fibres of the outermost layer. Thus, the shell of the egg is formed. The egg is finally discharged through a narrow portion of the oviduct, and finally from the external orifice.

The shell, although it has no visible pores, is still permeable to air, a condition essential to the future development of the embryo, for it has been found that if the shell be covered with a layer of varnish, the egg dies. The ovum of the bird contains all that is necessary to perfect the embryo, and it receives no further nourishment from the mother. On this account it is furnished with a much larger amount of albumin and yolk, which are metamorphosed by cell growth, into the tissues of the chick. During this metamorphosis some chemical change is continually going on, and material, such as watery vapour, must pass out through the shell, for the egg is daily losing weight. Soon after the egg is passed, a small quantity of air passes through the shell at the rounded extremity, and accumulates between the internal and middle fibrous membranes. The vitellus or yolk, being lighter than the albumin, rises towards the surface of the egg, with the cicatricula uppermost, so that in whatever situation it may be placed, it is next the warm body of the mother during the hatching period. The three embryonic sacs are also developed in the egg, and the allantois, at an advanced period of incubation, lines nearly the whole of the shell. By this sac, the chick breathes ; for it has been shewn by Baudrimont and Ange,* that during eighteen days' incubation the egg absorbs nearly two per cent. of its weight of oxygen, while the quantity of carbonic acid exhaled from the sixteenth to the nineteenth day amounts to three grains in twenty-four hours. At length the chick is strong enough, partly by means of its beak, and partly by its struggles, to break its covering and escape.

CHANGES IN THE UTERUS WHICH FOLLOW FECUNDATION.

We have now to consider the changes that take place in the uterus after fecundation. As the ovum descends the Fallopian tube, the uterus is being prepared for its reception. The mucous membrane of the uterus contains numerous small tubular glands or follicles, and it is covered with ciliated epithelium. On impregnation, the mucous membrane becomes more vascular, increases in thickness, and bulges into the cavity of the uterus in the form of small rounded processes. The glands also increase in size, and pour out a copious secretion. This thickened mucous membrane is called the *decidua vera.* When the ovum reaches the cavity of the uterus, it becomes entangled in the decidua vera, a portion of which is rapidly developed round it. This latter portion is the *decidua reflexa,* so called because it is reflected over the ovum. At this stage the ovum is covered by the shaggy coat of the chorion. The villous tufts of the chorion are pushed into the follicles or glands of the two decidua, and absorb from these glands a nutritious fluid for the support of the ovum. But as the fœtus is further developed, a larger supply of nourishment is necessary, and the blood of the fœtus must be brought into nearer relation to that of the mother. This is accomplished by means of an organ called the *placenta.*

Formation of the placenta.—As already mentioned, the villi of the chorion disappear, except at a particular portion of its surface—the portion opposite to the allantois. This is the situation of the future placenta. This organ consists essentially of a fœtal and a maternal portion. The *fœtal* part is formed by the villous tufts of the chorion, containing loops of capillaries derived from the allantois. It is connected with the fœtus by the umbilical cord, and both it and the cord are covered by a reflection of the amnion. The *maternal* portion consists of the decidua, or hypertrophied mucous membrane, containing the uterine follicles. As already explained, these follicles become much enlarged, so as to allow the tufts of the chorion to be pushed into them, and at the same time the blood-vessels or veins ramifying on the outer surface of the follicles rapidly increase in size, and thus form large sinuses, termed the *uterine sinuses.* These sinuses exist in the decidua, not in the wall of the uterus, and they and the uterine follicles mould themselves over the outer surface of the villous tufts of the chorion, as seen in Plate XVII. fig. 8, *a*, *b*, *c*, *d*. Thus the blood of the fœtus is in close proximity to that of the mother, but is separated from it by the following membranes, which become more or less fused together: first, the wall of the fœtal capillary (Plate XVII. fig. 10, *g*); second, the chorion (*e*, *f*); third, the wall of the uterine follicle (*b*); and fourth, the wall of the uterine sinus (*a*). According to Goodsir, there are two layers of cells between the fœtal and maternal portions of the placenta,—first, a layer on the lining of the uterine sinus, *b* (*external cells*); and second, a layer on the chorion, *e*, *f* (*internal cells*). The function of the external cells is to absorb nutrient matter from the blood of the mother, while that of the internal is to absorb this matter from the external, and pass it into the blood of the child.* Through these membranes, the blood of the fœtus receives nutritious matter from, and gives up impurities to, that of the mother, probably by processes of endosmose and exosmose. During pregnancy, the involuntary contractile fibre of the uterus becomes gradually hypertrophied so as to increase the power of the uterus.

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* Du Dévelopement du Fœtus. Paris, 1850, p. 143.

Parturition.—The process of parturition takes place a few days beyond the end of the ninth calendar month. During pregnancy, the involuntary contractile fibre of the uterus is enormously hypertrophied. The fœtus is expelled by the contractile force of the uterus, aided by the abdominal and other muscles. It is soon followed by the expulsion of the placenta. When the placenta separates, the uterine vessels are torn across, but the orifices are speedily closed by the contraction of the uterus. The whole placenta, maternal and fœtal, including the uterine sinuses, uterine glands, and tufts of the chorion, separates, and the hæmorrhage which usually takes place does not come from the uterine vessels, but from the large sinuses in the placenta. After parturition, the muscular walls of the uterus atrophy by fatty degeneration, and the mucous membrane is renewed.

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* Goodsir. The Structure of the Human Placenta. "Anatomical Memoirs," p. 445.

General conclusions.—Such is a general sketch of the various stages of the function of reproduction, a study of which in the different classes of animals has led to the formation of various ingenious hypotheses, whereby it has been sought to bring the order of evolution within the operation of certain laws. One of these, which has excited great attention, is, that the human fœtus passes through transition periods resembling in turn the different inferior beings of the animal scale: that is to say, it at first resembles a zoophyte, then a mollusc, then a worm, a fish, a reptile, and so on. Thus the monads found among the inferior animals have been supposed to be represented by the germinal vesicle. The yolk, when divided, has been thought to resemble a gonium or a volvox. When the primitive groove closes, it has been likened to a worm; afterwards to a molluscous animal; and when the visceral arches appear, to a fish; and so on. This method of viewing the phases of development has led to a generalisation thus expressed by Serres,—viz., that "Human organogenesis is a transitory comparative anatomy, as in its turn comparative anatomy is a fixed and permanent state of the organogenesis of man." But that the human embryo ever resembles a worm, a mollusc, reptile, fish, or bird, can, on careful examination, nowhere be recognised. It is true that at one period all ova resemble each other; but it is equally certain that from the first moment of their formation they are impressed with a power of developing themselves in a certain direction, so that the ovum of a reptile, fish, or bird, will always be developed into similar animals, and by no concurrence of circumstances will ever be transformed into different ones. Neither is there any anatomical or structural relation between hem, for the visceral arches in the human fœtus are in no vay, as has been supposed, analogous to the branchiæ or lungs f the fish, for the former are partly transformed into the bones f the face, while lungs originate in inflections of the mucous ayer. The theory, then, may be considered as more fanciful han real, and founded upon loose analogies, which, instead of eing strengthened, are weakened as development proceeds, nd the true types of such analogies become more evident.

Lactation.

The most natural food for the infant is the milk of the mother. This fluid is secreted by special glands termed the *mammary glands.* In the human female, they form two rounded masses, the breasts, placed one at each side on the front of the thorax. They are essentially compound racemose glands, resembling in structure the pancreas and salivary glands. They consist of a number of lobes or lobules, from which proceed about fifteen or twenty ducts, called *galactophorous ducts.* These converge towards the areola, or circle round the prominence, or nipple, where they form *sinuses.* From these sinuses, small ducts pass to the surface of the nipple, where they open by separate orifices. When examined by a high power, the small vesicles and ducts of the gland are found to consist of a wall of areolar tissue lined by a mucous membrane, having tasselated epithelium. They are usually filled with molecular matter. The secretion of milk commences during the latter period of pregnancy, but it is not fairly established until two or three days after delivery. Its appearance is usually ushered in by a feverish condition, "*milk fever.*" The fluid secreted during the first few days after delivery is of a yellower colour than that secreted afterwards, and is termed *colostrum.* This milk is elieved by some to act as a natural purgative to the infant. Afterwards the milk is white, or bluish white, opaque, has little r no smell, and a slightly sweet taste.

Histological structure of milk.—When a drop of milk is xamined with a magnifying power of 250 diameters, it is ound to consist of a fluid in which there are numerous globules f various sizes, varying from the 1/2500 to 1/1500 of an inch in iameter (Fig. 1, p. 404). These globules are very refractive.

They are often in groups, but in healthy milk readily roll upon one another. On the addition of acetic acid they may be seen melting together, so as to form larger globules, which may then be dissolved by ether. Thus we learn that each milk globule consists of an envelope of albumen surrounding a drop of oil, and an appearance very similar to milk can be artificially prepared by first forming the *Haptogen membrane of Ascherson*, as already described at p. 36, and then rubbing the covering glass with a circular motion, so as to break up the membrane. Colostrum is found to contain, in addition to the ordinary milk globules, numerous large, irregular, globular bodies, from the 1/1100 to 1/800 of an inch, termed "*colostrum corpuscles.*" They contain numerous minute oily granules (Fig. 2).

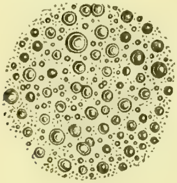

Fig. 1.

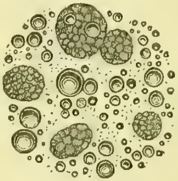

Fig. 2.

Chemical composition of milk.—The specific gravity of human milk is about 1032 (*Simon*). It is usually alkaline, sometimes neutral, but it gradually becomes acid. When it has stood for a time, the globules float to the surface forming a layer called *cream*, while beneath we have a bluish-white fluid, poorer in fat, but having a higher specific gravity than the upper stratum. If the temperature is cool, and the atmosphere not highly charged with electricity, milk will remain in its natural condition for several days; but under reverse conditions, it spontaneously coagulates. This coagulation is caused by part of the milk sugar undergoing acid fermentation, yielding lactic acid, which precipitates the albuminous constituent of milk—the casein.

$$\left(\underset{\text{Milk Sugar.}}{C_{12}H_{20}O_{10}} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Lactic Acid.}}{4(C_3H_6O_3)}\right)$$

The following are analyses of human milk, compared with that of a few other animals, in 1000 parts:*

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* Article "Milk," in Watt's Dictionary of Chemistry, vol. iii.

Constituents.	Human—*Vernois* and *Becquerel.*	Human, 3d day after delivery—*Simon.*	Cow—*Chevallier* and *Henry.*	Ass—*Chevallier* and *Henry.*	Ewe—*Chevallier* and *Henry.*
Water . . .	889·08	828·0	870·2	916·5	856·2
Sugar . . .	43·64	70·0	47·7	60·8	50·0
Casein and extractives	39·24	40·0	44·8	18·2	45·0
Butter . .	26·66	50·0	31·3	1·1	42·0
Salts . . .	1·38	3·1	6·0	3·4	6·8
TOTAL,	1000·00	991·1	1000·0	1000·0	1000·0

It will be seen from the above table that ewe's milk is the richest of all milks, while the milk of the ass is rich in sugar, but poor in butter and casein. It will also be observed that human and cow's milk are, on the whole, much alike, and hence the last may be substituted for the first. The human milk examined by Simon soon after delivery was rich in sugar and fat, the amount of the latter being nearly double that found in ordinary milk. Vernois and Becquerel found in the ash of human milk 6·9 per cent. of calcium carbonate, 70·6 per cent. of calcium phosphate, 9·8 per cent. of sodium chloride, 7·4 per cent. of sodium sulphate, and 5·3 per cent. of other salts.

Milk is often adulterated with water, flour, brain-substance, almond emulsion, chalk, &c. These adulterations may be readily detected by microscopical examination.

PARTHENOGENESIS.

By parthenogenesis (from παρθενεὶα, virginity; γένεσις, generation) we understand the production of offspring, unlike their parents, which *may* take place without a true act of fecundation, that is, without at each birth, a necessary union of the male and female elements. This process had been previously called by Steenstrup, *alternate generation.* But many of the facts described under this term refer not so much to an alternate as to a continuous development. Thus, many insects spend part of their lives as a worm, and part as a moth. The moth produces the worm, and the worm produces the moth; but this is not an alternate, but a different phase of the same generation. So a correct knowledge of the development of the *Medusa aurita* has shewn that what naturalists had considered to be four distinct animals are in fact only different stages in the development of one animal. The formation of the Aphis is especially alluded to by Steenstrup. Several of these insects are produced from the mother, and each may produce others, although it is only certain of them which become transformed into a fly. But the generation of a plant may be called alternate in the same sense as it is used in the case of the Medusa or the Aphis, inasmuch as the seed produces a root and a leaf-bud, which proceed to develop other leaves before they finally produce flowers with seed like that from which the plant originated. The term *parthenogenesis*, therefore, proposed by Owen, is the more correct one, and the following are examples of this process :

1. *The development of the Tape Worm, &c.*—The researches of Helminthologists, but especially of Siebold, Van Beneden, Dujardin, Steenstrup, and Blanchard, have cleared away the mystery which has so long hung over the origin of tape worms and other entozoa. It seems now determined that tape worms are only further stages of development of cysticerci, as flukes are only further stages in growth of certain cercariæ.

Professor Siebold first pointed out that the *cysticercus fasciolaris* found in the liver of the mouse, reaches its ultimate stage of development in the intestines of the cat, and is there transformed into the *tænia crassicollis*. This fact was confirmed by a careful series of observations made by Dr Henry Nelson, who, in his thesis presented to the University of Edinburgh in 1850, carefully traces and figures all the various stages which the tape worm of the cat passes through. Each joint of this worm is estimated to contain 125,000 ova, which gives for the entire animal about 12,500,000. These minute bodies pass off by the fæces in incalculable numbers, and enter into the body of the mouse, mixed with its food or drink, or by licking its furry coat, to which they adhere. From the alimentary canal of the mouse they may enter the liver of that animal in three ways—1st. They may ascend the bile ducts. 2d. They may pass through the coats of the intestine, and penetrate the adjoining portion of the liver. 3d. They may bore their way into one of the mesenteric veins, and be carried by the blood along the vena porta to the liver. Dr Nelson considers the latter to be the most correct view, as he shews that the ova are furnished with temporary teeth, which enable them to pierce the tissues. That they do not perforate the intestine, and so get into the liver, is shewn by the fact that they are most developed on the surface of that organ, and least so in its interior. Neither are they found especially in the biliary ducts, like the *distomata.* Hence the blood seems to be the channel of their introduction, an idea still further supported by facts, the number of which is rapidly augmenting, demonstrating entozoa in various stages of development existing in the blood itself. Arrived at the liver, these ova are transformed into *cysticerci fasciolares*, and would never proceed further in development in the mouse, but being eaten by the cat, they become tape worms, and are transformed into *tæniæ crassicolles.*

This series of observations renders it probable that all the various kinds of tœnia are only advanced stages of development of different cysticerci. Dr Nelson points out that "the head of the *cysticercus cellulosæ* resembles in every respect that of the *tœnia solium* of man. The two figures given by Bremser are identical, if we allow for the stretching of the neck in the latter. Both have a double circle of hooks ; and although the *tœnia solium* is sometimes found without any teeth, Bremser has fully proved that this is the result of age, and not the original condition. He also observed, that as the worm increased in age, one row of the double corona first fell off, and was after a time followed by the other, leaving the worm thus unarmed." Besides, man feeds on animals in which these cysticerci are common, especially on the pig and sheep ; and it has been observed that in countries where meat is often eaten raw, as in Abyssinnia, tape worms are very common. The reason of the rare occurrence of tœnia in civilised countries is probably owing to the cooking of food, which destroys the vitality of the cysticerci. Occasionally, however, it may easily be conceived that, owing to meat being very underdone, or to the tenacity of life in certain of these creatures (many of them resist a high temperature without injury), they may escape the action of the teeth, arrive living in the human stomach, and be converted into young tœnia.

These ideas with regard to the origin of tape worms have been converted into certainties by the experiments of Dr Küchenmeister.* He fed dogs and cats upon parts of animals which contained different kinds of cysticerci, and subsequently found the tape worms into which these had been transformed presenting various stages of development, according as the life of the animal which had eaten the cysticerci was more or less prolonged afterwards. Every precaution seems to have been used in these experiments, one of which may be cited. An old dog, during a period of from six to eight weeks, was frequently purged with castor oil, so as to prevent the possibility of tape worms being present. On the 18th of March 1851, he ate food containing ten cysticerci. On the 25th, he ate as many more, and on the 1st of April several others which were not numbered. On the 10th of April the dog was killed, and thirty-five tœnia were found in the intestines, of which five were from 124 to 390 millimetres (from about 5 to 15 inches) in length, and possessed from 130 to 160 joints. There were six others from 25 to 96 millimetres (1 to 5 inches) in length, having from 40 to 60 joints. There were twenty-one others which measured from 8 to 16 millimetres ($\frac{1}{4}$ to $\frac{1}{2}$ an inch) in length, in which the joints were so indistinct that they could not be counted. Lastly, there were three measuring from 4 to 5 millimetres (1-6th of an inch) in length, in which the joints could scarcely be distinguished. Considering the power of contraction and elongation possessed by these worms, their length was not so decided a character of their stage of development, as the size of the head and hooks, which corresponded to the three periods in which the cysticerci had been swallowed.

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* *Prague Vierteljahrschrift,* Band i. 1852, p. 126.

On feeding dogs upon the liver of the mouse, containing the *C. fasciolaris*, Dr Küchenmeister never found tœnia in the intestines. But when he fed cats on the same liver, the intestines contained the *tœnia crassicollis.* This observation indicates that not only are certain cysticerci transformed into certain tœnia, but that the former require certain habitats, or peculiar animals in order to undergo this transformation. Although the present amount of our knowledge does not enable us to state from what kinds of cysticerci many species of tœnia are formed, it seems tolerably certain from the observations of Siebold, Nelson, and Küchenmeister that the *Cysticercus fasciolaris* of the mouse is transformed into the *Tœnia crassicollis* of the cat; the *C. pisiformis* of hares and rabbits into the *T. crassiceps* of the fox; the *C. tenuicollis* of ruminantia and squirrels into the *T. serrata*, so common in the dog, and the *C. cellulosæ* of the pig and sheep, into the *Tænia solium* of man. It is also tolerably certain from the observations of Eschricht that the *Bothriocephalus latus* of man found in certain countries, especially in Russia, is the further development of a species of *Ligula*, which exists in large numbers in the flesh of the dorse, and other fish of the northern seas. Dr Cobbold has shewn that the *T. medio-canellata* is, in fact, the most common tape worm of man, and that it infests the ox and enters the human family by the process of eating beef.* It has no circlets of hooklets, but four suckers.

The importance of the head of tape worms, so long recognised by practical physicians as the only certain proof of the complete expulsion of the worm, has also received an explanation from the researches of Helminthologists, into the anatomy and development of these animals. Notwithstanding the doubts expressed by Van Beneden as to the lateral canals being connected with the digestive system, and his notion of their being peculiar secreting organs, Dr Nelson in his thesis has distinctly traced them into the suckers of the *tænia crassicollis.* From each of the four suckers a canal descends, which afterwards unite, two and two, to form the lateral canals. He also carefully describes the manner of feeding and propulsion of the contents of these canals from the cephalic to the caudal segment. Hence the head is important as the means by which the animal is nourished.

But the head is also important, as pointed out by Van Beneden, as the part from which all the joints are thrown off, by gemmiferous reproduction, those formed first being pushed downwards, and being further developed as they go. Hence, why the joints are narrow near the head, and become larger and longer near the tail. The latter after a time separate, but according to Van Beneden, may still go on developing, and become, he thinks, a species of fluke or distoma. In fact, he considers a tape worm as a compound fluke worm, the whole consisting of three stages or periods: 1st, the cystic head (*Scolex*) ; 2d, the compound tape worm (*Strobila*) ; 3d, the separated joints (*Proglottis*). This latter view, however, is opposed by the observations of Steenstrup as to the development of the fluke, as much as by what we know of the arrangement of the nervous and digestive systems of this entozoon.

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* Spencer Cobbold, Tapeworms. 1866. Appendix.

2. *The development of the animals forming coral reefs.*—These reefs are banks or walls of hard materials, growing from a definite depth to near the surface of the water. They are entirely the work of marine animals, belonging to the class of Polyps (sub-kingdom *Cœlenterata*). These form communities, growing up in the same way, budding side by side or dividing, and while so multiplying remaining united together, so as to form a larger and larger mass. The buds are so arranged that the ends have a hemispherical form, or appear like branches dividing and subdividing. This is owing to the manner in which the new individuals unite with one another. Each species of Polyp has its own peculiar mode of budding, branching, and ramifying, giving to it as distinct an appearance as exists among different trees. The number of these different species is very great, and they all have not only peculiar features and habits, but require different positions in the sea. There are those which are only found in shallow waters ; others again in water two fathoms deep ; others are never found in waters which are less than five or six fathoms deep ; and others only in waters at least ten fathoms deep. These peculiarities are as marked among corals as the differences we observe in the distribution of plants and trees on mountain slopes, or among animals in different localities. The mere fact of the water being more or less clear is enough either to foster their growth or cause their destruction. The animal made of such soft and tender materials must be very nicely and evenly adjusted in its structure to be able to bear the pressure of a particular depth and no other. Hence why those who live near the surface cannot exist a few fathoms deep ?

A coral reef, then, is a structure built up from a definite depth, successively and gradually, not by one kind of coral, but by a great variety of kinds, combining together and forming by their joint work a wall, which, from a given depth, may end in reaching the surface of the water. And while it is growing, this wall is all the time changing its builders. It is not one kind that commences and completes the structure to the summit. One kind does a part of the work, and then ceases ; another kind comes in and continues the work for a while, and ceases in its turn ; and so on, till it is completed.

Suppose we have a slanting shore, and that at 600 feet distance from the shore the depth is 10 or 12 fathoms, the animals would commence building a wall, steep towards the ocean, slanting gently towards the shore, rising in the end towards the level of the water. The effect of muddy water, occasioned by storms and tides, raising the sand and mud at the shore, is to destroy the corals near the shore and prevent the building of the reef. On the other hand, where there is a somewhat steeply slanting shore, and the water is pure and plentiful, the conditions are most favourable to the animals. Consequently the side towards the sea will be built almost vertically, and will grow more rapidly than that towards the land.

It having been ascertained that different portions of the reef, at varying depths, are built by different species of corals, and that these are immovably attached together, the question arises, Whence did these new corals come which built the later portions ? It is now known that this results from free polype ova becoming fixed and presenting simply various degrees in development as they attach themselves to different elevations on the reef. In each degree of development, however, a similar form may be reproduced without a new act of fecundation.

This story of the coral reef, as an example of parthenogenesis among animals, would not be complete without a reference to what it teaches us of the chronology of the earth. Now, Agassiz has determined that on the southern coast of Florida, within fourteen years, the addition in the way of a crust of corals found upon the foundations of Fort Taylor, does not exceed one inch in depth ; therefore, less than a foot would grow in a century, and this he considers is overstating the rate of growth. It would take, therefore, six thousand years to produce a reef 60 feet high, which is the known depth of the inner coral reefs on that coast. But outside these are other reefs which must have grown since the internal ones were formed, because without the existence of the former, the coast could not have presented the conditions necessary for their production. But the outer reefs are as thick as the inner, and must also have taken six thousand years to grow. But an examination of the shore proves that it also is an ancient coral reef, and for the same reason must have been formed before the coral reefs nearest the coast; in that we have a third item of six thousand years to add to its chronology. Further, within the shore on the Indian hunting grounds are eminences called hummocks, which are also coral reefs concentric with the shore, and formed of the same species of corals as those now building the internal reefs. So that, if there be any accuracy in these two leading facts, viz., that the rate of growth is less than a foot in a century, and that the existence of an outside reef precludes the formation of a reef inside, we have the evidence, in the existence of these four consecutive reefs, that twenty-four thousand years ago there was a sea washing the plain where those hummocks are, and that no reef had then formed beneath them.

Yet this is not all. These animals are of the same kind as those that live now, and what has been described occurs within a narrow track of fifteen or sixteen miles. Sixty miles in the interior is a lake, up to the shores of which the ground consists of similar hummocks formed of coral. Nay more, the whole peninsula of Florida is entirely made up of coral reefs, and if so, we can scarcely escape the assumption that hundreds of thousands of years must have been required for the animals to build it. And yet, according to Agassiz, this must be nothing compared to the age of the world, because it is a period within which the species of animals which now live existed on the earth ! That is to say, in the mind of a geologist, altogether modern time !*

3. *The development of bees.*—The observations of a distinguished Apiarian, M. Dzierzon, of Carlsmarkt in Silesia, confirmed by the scientific researches of Professor Siebold as to the reproduction of bees, offers another illustration of Parthenogenesis.

In the hive, as is well known, there are three sets of bees, the queen-bee, the drones or male bees, and the workers, which have generally been called neuters, but they are, in fact, imperfectly developed female bees. The queen or female bee is only impregnated once, by one of the drones, while in the air, during what is called the nuptial flight. On this occasion she receives into a receptacle the seminal fluid, which is sufficient for the remainder of her days, and her impregnation may be known at once (as the receptacle formerly contained limpid fluid, whereas afterwards it is white and opaque). The receptacle or cavity lies apart from the ovary, but communicates with the oviduct, from which, however, it can be shut off at will.

The workers having prepared three kinds of cells, viz., drone cells, worker cells, and royal cells, each of which has its own peculiar form, and size, the queen proceeds to deposit an egg in each, laying at the rate of perhaps 200 a-day, or 12,000 in two months. In doing this she takes care to bring every one of those destined for the royal and the worker cells into contact with the seminal fluid, but takes equal care to keep free from such contact every one of those destined for the drone cells. She is probably guided in this by the feel of the individual cells which she visits, the requisite proportions and number of which have been previously made by the workers. In due time the number of bees, increasing beyond the capacity of the hive to hold them, a swarm comes off, headed by the old queen, who leaves her place in the hive to be supplied by one of her royal daughters. The latter heads the next swarm, which commonly leaves the hive within from seven to nine days after the first, and during the nuptial flight, she is duly impregnated by one of the attendant drones. The like happens with the other swarms; and after the departure of the last, a struggle for the vacant throne ensues among the young princesses that remain in the hive, one of which succeeds in gaining it, while the others are all of them destroyed. The first thing done by the young queen is to get wedded, an affair seldom delayed beyond a day or two after her accession, and invariably celebrated in the open air, the queen leaving the hive for that purpose, accompanied by a crowd of drones, one of whom she selects, and returning to the hive after the consummation of the nuptials. Within a couple of days thereafter, she begins to lay, depositing the eggs with the precautions in respect of the seminal fluid already noticed, in order to maintain due proportion between the several sorts of bees.

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* See Agassiz on "The Structure of Animal Life," 8vo, 1866, p. 52, *et seq.*

But it occasionally happens unfortunately for the well-being of the community that from some defect in her wings incapacitating her for flight, a queen cannot leave the hive. Her nuptials, therefore, are not celebrated (and she remains a virgin). Possessing, however, all the fertility of a wedded queen, and the same propensity for reproducing the species, she proceeds to lay eggs notwithstanding, and none but drone bees resulting, the economy of the hive is subverted. Young workers and queens, it is true, make their appearance also; but they are the progeny of the old queen, who, just before her departure with the first swarm, had laid eggs which could be hatched only a little while in advance of those of her unhappy successor. As soon, therefore, as one of these young queens becomes competent for duty, she attacks the reigning sovereign, and takes possession of the throne. Thereupon a general massacre of the redundant workers and drones takes place, and the body politic is again restored to its natural condition. Sometimes a hive has no queen at all. In that case Leuckart found that if a worker bee be fed with royal food it is transformed into a queen. This consists of a peculiar paste prepared in the digestive organs of the workers instead of pollen and honey.*

Such are the facts from which it follows that male animals in insects may be produced independently of the union of the ova with spermatozoids, in the same way that buds are thrown out in trees, or new polype heads are formed, without a distinct act of generation. Unimpregnated ova in insects are analogous to the successive buds in a tree, which are annually capable of being fertilised, although they are not all so. The queen, in this respect, is like a tree, uniting two modes of development—seminal or oviviparous, and gemmiparous. She is a female in form only, not in reality. She has the appurtenances of a female, but the attributes of a male ; and is, in fact, a male in a higher sense than even the drone. She is a *typical* bee, adequate of herself to reproduce her kind in its highest, which is the male form, and requiring only the co-operation of an ordinary male to reproduce herself in order to the production of those master bees which are the mainspring of the whole economy of the hive. Her ovary is, properly speaking, a *gemmarium*, the products of which she herself fertilises at will by shedding on the germs or ova the semen stored up in her receptacle.

4. *The development of the aphides, or plant lice.*—In 1745, Bonnet directed the attention of physiologists to the development of the aphides or plant lice, a process of true parthenogenesis.† At the close of summer the impregnated ova of the aphis are deposited in the axils of the leaves of the plant infested by the insect, and these ova are hatched the following spring, a wingless six-footed larva being produced. These larvæ will produce a brood of eight wingless larvæ like themselves without any connection with the male. No winged males are to be

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* See Siebold, On Parthenogenesis, translated by Dallas, 1857 ; also Harvey, On the Seed and the Bud, pp. 45, 6, 7.

† Bonnet : "Traité d'Insectologie, ou Observations sur les Pucerons," 1745.

ound at this period. This procreation from a virgin mother vill go on to the eleventh generation before the influence of he original impregnation has been exhausted. At this period, owever, individual growth obtains the mastery over the repro- luctive capacity, and some members of the last brood are hanged into winged males, while others become ordinary egg- earing females. These latter are impregnated by the males, nd then the process is repeated the following year.*

NATURAL SELECTION.

But while that peculiarity of reproduction, named partheno- enesis, is of great importance in enabling us to understand he numerous varieties of forms which exist among the inverte- rata, another principle—that of natural selection—has recently een referred to by Mr Darwin,† which helps us to account or the origin of species and the variations which exist among nimals, as the result of sexual generation. We have previously lluded to the fact that the external characteristic form is gene- ally determined by the male, while the bulk and internal ualities are dependent on the female. Of this there are many xamples.

1. *Hybrids between the horse and the ass.*—A male ass and a nare produce a *mule*, while a stallion and a female ass produce *hinny*. In the first case, the ears are long, the tail tufted, he feet small, and the animal brays. In the second case, the ead is that of the horse, with short ears, the legs coarse and trong, and the animal neighs.

2. *The case of the otter sheep.*—Another remarkable example s that of the Ancon, or otter sheep. "A farmer in Massachu- etts possessed a flock of fifteen ewes and a ram of the ordinary ind. In the year 1791, one of the ewes presented her owner vith a male lamb, differing from its parents by a proportionally ong body and short bandy legs, whence it was unable to emulate ts relations in those sportive leaps over the neighbouring ences, in which they were in the habit of indulging, much to he good farmer's vexation. His neighbours imagined that it vould be an excellent thing if all his sheep were endued with he stay-at-home tendencies inforced by nature upon the newly-

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* Owen, On Parthenogenesis, p. 24. 1849.

† Darwin, On the Origin of Species by means of Natural Selection, or the Preser- ation of Favoured Races in the Struggle for Life.

arrived ram, and they advised Wright to kill the old patriarch of his fold, and instal the Ancon ram in his place. The result justified their sagacious anticipations. The young lambs were almost always pure Ancons, or pure ordinary sheep; and when sufficient Ancon sheep were obtained to interbreed with one another, it was found that the offspring was always pure Ancon." In this well-authenticated instance we have a distinct race established at once, or by a leap, and that race breeding true. When the Ancon sheep were herded with other sheep they kept together, so that it was believed that this breed might have been indefinitely protracted, had it not been superseded by the introduction of the Merino sheep, which were not only superior to the Ancons in wool and meat, but were equally quiet and orderly.*

3. *The case of Gratio Kelleia.*—A Maltese of the name of Gratio Kelleia was born with six fingers upon each hand, and six toes upon each foot. He married a lady having the usual number of fingers and toes. The result of the marriage was four children: the first, Salvator, had six fingers and six toes; the second, George, had five fingers and toes, but one was deformed; the third, Andrè, had five fingers and toes, perfect; and the fourth, a girl christened Marie, had five fingers and five toes, but her thumbs were deformed. These all grew up and married five-fingered and five-toed individuals. "Salvator had four children; they were two boys, a girl, and another boy: the first two boys and the girl were six-fingered and six-toed like their grandfather; the fourth boy had only five fingers and five toes. George had only four children: there were two girls with six fingers and six toes; there was one girl with six fingers and five toes on the right side, and five fingers and five toes on the left side, so that she was half and half. The last, a boy, had five fingers and five toes. The third, Andrè, you will recollect, was perfectly well formed, and he had many children whose hands and feet were all regularly developed. Marie, the last, who, of course, married a man who had only five fingers, had four children: the first, a boy, was born with six toes, but the other three were normal. . . . . Now, what would have happened if these abnormal types had intermarried with each other—that is to say, suppose the two boys of Salvator had taken it into their heads to marry

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* Huxley: Westminster Review, 1860. Article on Darwin, "On the Origin of Species."

their first cousins, the two first girls of George, their uncle? You will remember, that these are all of the abnormal type of their grandfather. The result would probably have been, that their offspring would have been in every case a further development of that abnormal type. You see it is only in the fourth, in the person of Marie, that the tendency, when it appears but slightly in the second generation, is washed out in the third; while the progeny of André, who escaped in the first instance, escape altogether."*

4. *The case of Lambert, the porcupine man.*—Another example of hereditary transmission is the remarkable case of Edward Lambert, "the porcupine man."† In 1755, he was about forty years of age. His skin seemed like a "dusky-coloured thick case, exactly fitting every part of his body, made of a rugged bark or hide, with bristles in some places." . . . . "The bristly parts, which were chiefly about the belly and flanks, looked and rustled like the bristles or quills of a hedgehog shorn within an inch of the skin." The remarkable point in this man's story, reports Mr Henry Baker, is, "that he had six children, all with the same rugged covering as himself; the first appearance whereof in them, as well as in him, came on in about nine weeks after the birth. . . . . It appears therefore past all doubt, that a race of people may be propagated by this man, having such rugged coats or coverings as himself; and if this should ever happen, and the accidental original be forgotten, 'tis not improbable they might be deemed a different species of mankind: a consideration which would lead one to imagine, that if mankind were all produced from one and the same stock, the black skins of the negroes, and many other differences of the like kind, might possibly have been originally owing to some such accidental cause." This man evidently suffered from a disease termed Icthyosis (ἰχθύς, ἰχθυος, a fish), an affection of the skin which he transmitted to his children, and according to another authority, to two grandchildren.

The principle of natural selection has been extensively applied by Mr Darwin to explain the origin of species. According to him, every animal and plant is capable of increasing with such rapidity, that if it were unchecked by other species, it would soon occupy the greater part of the habitable globe. But in the *struggle for existence*, few only of those which are brought into the world can obtain food and arrive at maturity. It must be evident that the weak succumb and the strong remain. We have the *survival of the fittest.* Now, slight accidental causes may occasion variations, which being transmitted become more and more marked and permanent, so that the various conditions which influence life—such as climate, locality, food, &c.—may influence the species of animals. In any given species, those alone survive which have some advantage over the others, and this is often determined by a slight peculiarity capable, in a severe competition, of turning the scale in their favour, such as the possibility of procuring food during the least favourable seasons, and of escaping the attacks of their most dangerous enemies. These peculiarities are transmitted, and thus we have a species. We have many admirable examples of the principle of selection in breeding, such as—

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* Huxley "On our Knowledge of the Causes of the Phenomena of Organic Nature. Six Lectures to Working Men." 1863. Pp. 95–97.

† "Philosophical Transactions," vol. xiv. No. 160, 1730, and afterwards in vol. xlix., part i., for 1755.

1. *The varieties of dogs.*—The numerous varieties of dogs, from the Newfoundland or St Bernard to the lap-dog or terrier, are believed by Darwin to be produced from not more than two or three wild species. John Hunter maintained that the wolf, the dog, and the jackal were all of one species, because he had found, in two experiments, that the dog would breed both with the wolf and the jackal; and that the mule, in each case, would breed again with the dog.

2. *The varieties of pigeons.*—From the common rock pigeon (*Columba Livia*) no fewer than 150 distinct races of domestic pigeons have been produced. These all have received names and breed true ; and at least twenty of them would be classed by an ornithologist, if he shot them in the woods, as well-defined species ; while extreme forms, such as the short-faced tumbler, the pouter, and the fan-tail, would not be placed in even the same genus as the rock pigeon. Among pigeons, pigeon fanciers can produce, by cross breeding, not only differences in outward form, but they find even the number and size of many of the bones changed.

Atavism.—It is remarkable that now and again we find in the offspring of all tame pigeons some peculiar characteristic of the rock pigeon, especially in the plumage. This reappearance of marks of an old progenitor is termed *atavism* (*atavus*, an old grandsire). Similar facts have been observed among other animals.

SEXUAL SELECTION.

Other circumstances have recently been pointed out by Mr Darwin as producing permanent differences in form among men and animals.* He believes that the sexual instincts and passions have a powerful influence. For example :

1. *Law of battle.*—Among animals there is a *law of battle*, that is, the males fight for possession of the female, and any male possessing a peculiarity giving him an advantage in the contest over his opponent, obtains the female, and in accordance with the law already stated (p. 415), transmits this peculiarity to his descendants. This holds good to the present day among barbarous nations. "There can be little doubt," writes Mr Darwin, "that the greater size and strength of man, in comparison with woman, together with his broader shoulders, more developed muscles, rugged outline of body, his greater courage and pugnacity, are all due in chief part to inheritance from some early male progenitor. These characters will, however, have been preserved or even augmented during the long ages whilst man was still in a barbarous condition by the strongest and boldest men having succeeded best in the general struggle for life, as well as in securing wives, and thus having left a larger number of offspring."†

2. *Voice.*—According to Mr Darwin, voice and musical powers are influential in reference to the propagation of the species. Among all Mammals, the males use their voice more during the breeding season than at any other time. The females use their voice as a love-call. The male Gibbon has a loud musical voice, and according to Owen, this anthropomorphic ape "may be said to sing." Mr Waterhouse thinks it highly probable it utters its musical notes during the season of courtship. "Women are generally thought to possess sweeter voices than men, and as far as this serves as any guide, we may infer that they first acquired musical powers in order to attract the other sex. But if so, this must have occurred long ago, before the progenitors of man had become sufficiently human to treat and value their women merely as useful slaves. The impassioned

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* Darwin, "The Descent of Man and Selection in relation to Sex," 1871.

† "Descent of Man," &c., p. 325.

orator, bard, or musician, when, with his varied tones and cadences, he excites the strongest emotions in his hearers, little suspects that he uses the same means by which, at an extremely remote period, his half-human ancestors aroused each other's ardent passions during their mutual courtship and rivalry." *

3. *Idea of the beautiful.*—It is well known that different races of mankind have different ideas of personal beauty, and that great care is taken of those individuals possessing it. Thus peculiarities are intensified and transmitted through many generations till they become permanent. Sexual selection has effected much in producing the high style of beauty found among the aristocracy of civilised nations. Members of wealthy families, in which primogeniture has long prevailed, chose from all classes the most beautiful women as their wives, and consequently their descendants become more handsome. Among certain tribes of negroes, according to Winwood Reade, the ugly women are continually eliminated and sold as slaves, a practice which, though morally wrong, has produced tribes remarkable for their "uniformly fine appearance."

Among men, both savage and civilised, many causes interfere with the action of sexual selection, but we know enough to confirm the opinion that in this matter man obeys the same laws as regulate inferior animals.

Such is a very brief account of certain of Mr Darwin's ingenious opinions. No one can peruse his works without recognising their high scientific value and the large number of facts brought to bear on the inquiry. Very few of those who ridicule Mr Darwin's ideas have ever read his books and examined the evidence he furnishes in support of his doctrines.

It has long been known that many diseases are hereditary; but it has recently been pointed out by Brown-Séquard that epilepsy induced in Guinea-pigs is often transmitted to their offspring, even when produced artificially. He has found that in these animals a morbid condition of the nervous system is caused by section of one lateral half of the spinal cord, or of the posterior columns reaching to the cornuæ of grey matter, or of the sciatic nerve, and also in some cases by the simple puncture of the spinal cord. Under any of these conditions, true epileptic attacks may be readily produced by pinching the skin of the cheek. Many Guinea-pigs survive the operation and breed; and in the young, convulsive attacks may be produced in the same way. Here we have a disease artificially produced, yet, nevertheless, faithfully transmitted.*

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* "Descent of Man," p. 337.

HETEROGENESIS.

By heterogenesis (from ἕτερος, diverse, different ; γένεσις) we mean the production of living beings without parents.†

History.—This subject has engaged the attention of physiologists since the days of Aristotle. He, as well as most of the naturalists who lived previous to the time of Harvey, were of opinion that dust, decomposed flesh, and other dead substances might, under the influence of heat, air, and water, give rise to vital organisms. This mysterious process, by a singular perversion of language, has been called spontaneous generation. Francis Redi, a physician of Florence, was the first who clearly demonstrated, in 1638, that the larvæ and worms found in a dead body were not produced by putrefaction, but originated from flies' eggs deposited in the flesh.‡ The researches into generation, of William Harvey, led him to announce the law, "Omne vivum ex ovo." Since his day the belief has been general, that all animals and plants are derived from eggs or seeds; that vitality is always transmitted, and never created; and that, where these fundamental principles cannot be recognised, the minuteness of the germs and their wide diffusion throughout nature, and more especially in the atmosphere, offer a sufficient explanation of what may appear mysterious. Nature, it was argued, must be uniform in her operations, and analogy warrants our supposing that the same law of generation which applies to the higher animals and plants, is equally applicable to the lower.§

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* Brown Séquard : Archiv. gén. de médecine. Fevrier, 1856. Vol. vii. p. 143. Mars-Avril, 1869, p. 211.

† Dr Bastian proposes the word Archebiosis (ἀρχή, beginning, and βίος, life) to express the production of living organisms from non-living materials, while Heterogenesis, according to him, is the production of living beings from pre-existing organisms living or dead. But all living creatures originate from organic matter which has once lived, such as the material dissolved in an infusion, according to the law of molecular organisation as explained (p. 46). I therefore regard it as better to define the terms Homogenesis, Parthenogenesis, and Heterogenesis, as they will be found in the text.

‡ "Experimenta circa Generationem Insectorum."

§ Most of the arguments on the other side, that is, in favour of Heterogenesis, will be found well stated by Burdach ("Physiologie," tome i. p. 8, *et seq.*)—arguments admitted by Allen Thomson "to throw the balance of evidence in favour of the spontaneous production of Infusoria, mould, and the like." (Todd's "Cyclopædia," article—Generation, vol. ii. p. 430. 1839.)

The ova, seeds, and primary cells, however, which were supposed to be floating in the atmosphere, though constantly looked for, even with the most powerful modern microscopes, can nowhere be found, and more careful investigation of the numerous forms of life which spring up in putrescent and fermented fluids have utterly failed in connecting them with pre-existing germs. Many scientific men, therefore, who had personally investigated the subject, were once more led into the belief in an equivocal or doubtful generation of the lowest forms of animal and vegetable life. This belief was strengthened by the appearance, in 1845, of a Memoir * by M. Pineau, carefully describing the evolution of organisms in the pellicle on the surface of infusions, and more especially in 1859, of a remarkable work by M. Pouchet, entitled "Heterogenesis, or Spontaneous Generation," as distinguished from Homogenesis, or Generation from Parents. This book contains numerous original experiments and observations made by the author, proving, as he thinks, that infusoria originate in a finely molecular, or, as he calls it, proligerous pellicle on the surface of decomposing fluids, without pre-existing cells or germs of any kind, and therefore independently of parents.

The publication of this book has led to a controversy which has continued up to the present moment. The theory of atmospheric germs, or that of the Panspermatists, has been sustained by M. Pasteur, who, by new experiments, has revived the doctrine that fermentation and putrefaction are not chemical processes, as has been maintained by Liebig, but physiological phenomena dependent on living germs derived from the atmosphere. These experiments have all, however, been since repeated by Pouchet and others, and their accuracy, as well as the correctness of his conclusions, are by them utterly denied. An extraordinary amount of research, ingenuity, and talent has been displayed by the advocates on either side, the results of which will be found recorded in numerous communications printed in the "Comptes Rendus" of the proceedings of the Academy.

Before stating more particularly the arguments advanced by the controversialists, on one side or the other, I propose describing shortly the results of some investigations undertaken by

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* "Recherches sur le developpement des Animalcules," etc. Ann. des Sc. Nat. (Zoologie) tom. iii. p. 182, and tom. iv. p. 103.

myself, with a view of determining precisely the facts of the case, and the nature of the phenomena which have excited so much discussion. In October 1863 I commenced a series of observations, with the aid of my former assistant, Dr Argyll Robertson, which were directed (1st) to determine with exactitude, by means of the microscope, the changes which occurred on the surface of infusions during the development of plants and animals there ; and (2d) to ascertain what influence the air treated in various ways exercised on such growths. These observations were carefully repeated and extended in October 1864. They were repeated, and numerous other experiments performed, with the aid of my late assistant, Dr Rutherford, in 1868 ; and my present assistant, Dr M'Kendrick, has also investigated the subject, and varied the experiments. These investigations naturally divide themselves into (1st) observations by means of the microscope as to the development of infusoria ; and (2d) experiments directed to destroy the supposed germs in the atmosphere, so as to prevent putrefaction.

1. *Mode of development of infusoria.*—This has already been described in detail (see p. 46).* Suffice it to say, in any vegetable or animal infusion there is first formed on the surface the *proligerous pellicle of Pouchet*, consisting of minute molecules. Two or more melt together to form a *bacterium*, and several bacteria unite end to end to form a *vibrio*.

The movements visible in the molecules and filaments vary according to the amount of development. At first the molecules which float loose in the fluid exhibit gyrations which cannot be distinguished from Brunonian movements. When short bacteria are formed, these exhibit peculiar vibrations,—often turn round on their own axis in various directions, and slowly change their place. They rarely dart rapidly through the fluid, or exhibit a serpentine motion. But when the vibrio is formed, the filament is pushed forward with greater or less velocity, at first presenting a wriggling, but, as it becomes longer, a more decided serpentine motion. A distinct flexure can be seen at certain points in the filaments, between the groups of molecular chains or filaments. Dumas says he has seen the molecules and bacteria uniting endways, a statement the correctness of which Pouchet doubts.* On two occasions, however, I was so fortunate as to see this occurrence.

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* The powers I have employed for the investigation were an excellent lens of one-eighth of an inch focus, by Ross ; but I also frequently used a one-twelfth of an inch by the same maker, and the immersion lens No. 10 of Hartnach, with varying powers of from 600 to 800 diameters linear. Occasionally I confirmed my observations with a lens made for me by Messrs Powell & Lealand, of one-twenty-fifth of an inch focus, whereby I obtained an enlargement varying from 1250 to 2000 diameters linear.

Pouchet thought that the vibriones exuded a mucous matter, whereby one stuck to the other. If so, such exudation can only be poured out at their extremities, as they only unite lengthways, never crossways. I feel satisfied, however, that the reason the actual union has so seldom been seen is, 1*st*, That it only occurs at certain periods of development, and can only be followed by the eye when the movements are slow; 2*d*, That amidst such a multitude of minute moving bodies it requires a long time before two can be found exactly on one plane, and can be brought so accurately into focus that they can be watched for a sufficient time. Having, however, in two instances, actually seen the coalescence, I can have no doubt whatever that such is the true method of elongation. Numerous other facts seen among elongated vibriones support this view.

The further development which takes place from histogenetic and histolytic changes in the proligerous pellicle, resulting in the production of various forms of animal and vegetable life, has been previously described (see p. 47). These are dependent on temperature, season of the year, exposure to sunlight, and nature of the infusion. In all these cases no kind of animalcule or fungus is ever seen to originate from pre-existing cells or larger bodies, but always from molecules.

According to Dr Bastian, in the proligerous pellicle composed of bacteria, embryonal areas gradually appear. As a result of segmentations in these, specimens of *Monas lens*, 1-3300th in diameter, more or less suddenly make their appearance; they increase in size, occasionally assume an amœboid appearance for a time, and are ultimately transformed into real amœbæ. A membrane is formed around them and they become encysted, and in the interior of some of them there springs up a progeny of new bacteria, the production of which occasions their final dissolution.† He also describes the formation of numerous fungi occurring in the pellicle at the same time.‡ That we should sometimes have animalcules, and at others fungi, is a well-known fact, the exact causes or conditions producing which are not yet explained. The Panspermatists, of course, are of opinion that the germs in the atmosphere are of many kinds, and that as they fall into various infusions they produce different results, in the same manner that varieties in ova or seeds develop themselves in peculiar localities or special soils. This assumption, however, seems to me opposed by the following experiment :—

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* Nouvelles Expériences, p. 115.

† Proceed. Royal Society, March 21, 1872. Vol. xx., p. 250.

‡ Bastian, The Beginnings of Life. Vol. ii. p. 232. 1872.

If an infusion be placed in a deep glass vessel, which again stands in the centre of a shallow vessel containing the same infusion, and the whole covered with a large bell glass, it will be found in eight days that on the surface of the former are numerous ciliated animalcules, while on that of the latter only bacteria and vibrios exist. The experiment may be reversed, for if the shallow vessel be filled to the brim, and the deep vessel has only its bottom covered, then the ciliated microzoa will appear in the former, and the non-ciliated in the latter.*

As a result of these experiments, Pouchet has formularised a law to the effect that the production of ciliated animalcules is in an inverse ratio to the square of the surface, and that the production of monads is in a direct ratio to the cube of the mass of the same fluid.† To this law I have met with some exceptions, animalcules having been produced in some of our recent experiments in the shallow dish, and vegetations in the deep vessel, and *vice versa.*

It is difficult to explain how germs falling from the air on the same infusion, under identically similar conditions, with the exception that the fluid is in vessels of different forms, can vary the results. Whereas the fact that the higher infusoria are formed secondarily out of the disintegrated mass of the simpler ones, which can only take place where that mass is considerable, and floating on the surface of deep fluids, directly confirms the molecular theory of growth, and offers an illustration of how successive disintegrations give origin to different formations ‡ (p. 46).

That the infusoria originate and are developed in the molecular pellicle which floats on the surface of putrefying or fermenting liquids, has been admitted by all who have carefully watched that pellicle with the microscope, more especially by Kutzing,* Pineau,† Nicolet,‡ Pouchet,§ Jolly and Musset,‖ Schaaffhausen,¶ Mantegazza,** and Bastian.†† The question therefore is, Are the molecules that constitute that pellicle derived from the air or the fluid,—are they precipitated from above, or do they float to the surface from below, like the globules of the milk which produce cream?

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* Pouchet's Nouvelles Expériences, &c., pp. 135, 243-245. Paris, 1864.

† Nouvelles Expériences, p. 134.

‡ See On the Molecular Theory of Organisation, by the Author. *Proceedings of Royal Society of Edinburgh*, 1861.

Now, it was in consequence of having professed to demonstrate what had escaped all previous observers—viz., the germs in the air—that M. Pasteur has made his name so famous. He tells us ‡‡ that he did this by causing a current of air to pass through a glass tube in which a pledget of gun-cotton had been placed. This was then dissolved in ether, and the sediment allowed to collect in a watch-glass. This sediment, after being repeatedly washed, and allowed to remain in distilled water for twenty-four hours at a time, is allowed to dry. A portion of the dried matter is then put upon a slide moistened with a weak solution of potash, and, being covered with another glass, is examined with the microscope. The results he has figured; and, very properly, he has given the scale of magnifying power under which they were drawn (Fig. 5), and which, by careful measurement, I have ascertained to be 180 times linear. His drawings, carefully copied, are represented (Figs. 1 to 4).

Fig. 1.

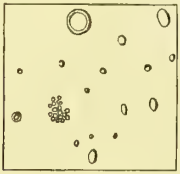
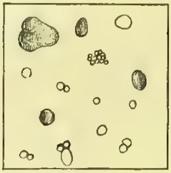


Fig. 2.



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* See Schaaffhausen, Comptes Rendus, tom. liv. p. 1046.

† Annales des Sciences Naturelles, 3me série, tom. iii. p. 182. This observer thinks he saw disintegrated fibres of meat and of other substances formed directly into vibriones,—in this he was incorrect.

‡ Arcana Naturæ, tom. i. p. 2.

§ Hétérogénie, p. 353. Nouvelles Expériences, p. 111.

‖ Comptes Rendus, tom. i. p. 934.

¶ Ibid., tom. liv. p. 1046.

** Institut Lombard, 1852, tom. iii.

†† Beginnings of Life. London. 1872.

‡‡ Annales des Sciences Naturelles, 4me serie, tom. xvi. p. 25.

Fig. 3.

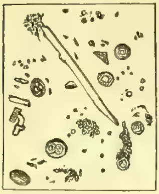

Fig. 4.

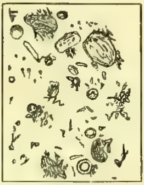

Fig. 5.

Exact copies of the figures given by M. Pasteur of the dust he collected on gun-cotton, magnified 180 diameters. These should be compared with Fig. 10 (Plate II.), magnified 800 diameters, shewing what is seen to take place when infusoria are forming. Fig. 5, scale of one hundreth of a millimètre.

He says Figs. 1 and 2 represent organised corpuscles from dust collected in twenty-four hours, from the 16th to 17th November 1859. The manner in which these drawings, giving the volume and outline of the bodies, were made, is as follows: "After the dust has been prepared in the manner described, I took a portion of it from the watch-glass, and diluted it with a solution of potash, consisting of 5 parts of potash in 100 of water. As soon as I perceived a globule evidently organised under the microscope, I drew it. This is how figure 4 was drawn."* This description leaves it uncertain whether an exact copy was taken of any portion of the field of the microscope, and, therefore, whether the figure represents the exact number of corpuscles present, and their relation to each other. It only gives their form. But, assuming that the same kind of demonstration was made in each case, we have the relative numbers of these bodies taken from the gun-cotton in Fig. 1. Fig. 2 is another demonstration of the same after the addition of an aqueous solution of iodine. Fig. 3 represents the organised corpuscles associated with amorphous particles obtained on the 25th and 26th of June 1860. Fig. 4, the dust of an intense fog in the month of February 1861. In all these demonstrations he admits the organised corpuscles are comparatively scarce, because, he observes (p. 31), it is frequently necessary to change the field in order to see one of them, whilst at other times several could be seen together.

M. Pasteur thinks that these drawings indicate the number of organised corpuscles that may be arrested in a small mass of cotton through which 1500 litres of air, in one of the less-frequented streets of Paris, have passed in twenty-four hours, about three or four yards from the ground. These he estimates at several millions in a litre (p. 29).

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* Annales des Sciences Naturelles, 4me série, tom. xvi. p. 25.

Now, it must be remembered that M. Pasteur is a chemist, and it will be admitted by every histologist that no method could be more unsatisfactory for determining either the nature or the number of the corpuscles than the one he adopted. The solution of the cotton in ether, the frequent soakings in water, the desiccation, and then the addition of a solution of potash, must completely alter the character of any living corpuscles in the atmosphere. Then the forms he assumes to be organic are not necessarily so. They are exceedingly frequent among mineral substances, and siliceous rounded forms are common, which, of course, resist sulphuric acid.

Nature of dust.—Numerous investigations have been made, both before and since M. Pasteur wrote, to determine the nature of dust floating in the atmosphere—of that dust, for example, which a ray of sunlight reveals to us, when admitted into a chamber. It consists, for the most part, of different kinds of starch corpuscles ; the debris of clothing, especially filaments of cotton, silk, and wool ; the results of different kinds of combustion, whether of coal or of wood ; various mineral bodies, globular or ovoid, amorphous or crystalline ; and minute fragments of insects and vegetables ; very rarely small seeds and microscopic animalcules.

These constituents vary to such an extent in different localities, as to enable the observer, in some cases, to determine whence the dust was collected. Starch corpuscles abound in the neighbourhood of flour-mills and bakeries ; fragments of clothing where there have been crowded assemblies of persons, cotton and wool being predominant if the persons belong to the poorer classes, and silk if the upper classes have been present ; the products of combustion predominate in smoky localities ; mineral particles on the roads and highways ; seeds, fragments of vegetables and insects, in market places, gardens, &c. &c. But although these constituents of the air vary in different places, infusoria, produced in all of them, are identically the same.

This has been tested in various ways. The dust has been ransacked to discover organic germs,—collected and carefully examined with the microscope, near the soil, and on the summits of the highest buildings, not only in frequented, but in desert places; in crowded assemblies, as well as in empty Gothic cathedrals and ancient vaults—in the ancient palace of Karnack, on the banks of the Nile, in the tomb of Rhamses II. at the extremity of the Desert, as well as in the central chambers of the great pyramid of Ghizeh. The chief element of the dust collected in these places has been found to be starch corpuscles.* Large quantities of air have been drawn through tubes by aspirators, and collected on cotton, in distilled water, or projected on glass. The feathery snow, which, falling through the atmosphere, may be well supposed to collect its contents, has been melted, and the precipitate carefully collected. The emanations of marshy places, such as those of the Maremma in Tuscany, have been specially investigated.† The larynges and mucuous pulmonary surfaces of numerous animals have been explored, even to the inmost bone cavities of birds. On the summit of Mont Blanc, amidst eternal snow; on the glaciers of the Jura and of the Pyrenees, and in the deep crevasse;‡ on the burning plains of Egypt, and in the markets of Constantinople, the dust of the atmosphere has been microscopically examined,—and in all with a like negative result as to the existence of germs. Nowhere could they be seen, or if a few, in the opinion of some, were visible, could they in any way account for the multitude of minute infusoria, which, in all these localities, not only readily spring up in putrid fluids, but in every instance are identically the same.§

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* Pouchet's Nouvelles Expériences, p. 73, *et seq.*

Histological proof that infusoria originate in the coalescence of molecules formed in fluids.—From what has been previously said it follows that the pellicle that may be seen to form on the surface of infusions cannot possibly be derived from the dust of the air, as it bears no relation whatever in structure to dust. Nor can it be derived from the bodies figured by M. Pasteur as existing in the atmosphere. (See Figs. 1, 2, 3, 4, p. 426.) For how, it may be asked, could these bodies produce the incalculable millions of minute molecules in the smallest fragment of the proligerous pellicle we can transfer to our microscopes, in which, as we have seen, the infusoria originate (p. 46)? It has been supposed that on falling from the air, they undergo rapid division, and spread over the surface with the greatest rapidity; but no one has ever seen this remarkable phenomenon, and the slightest consideration must shew that such an assumption is completely adverse to what can be readily demonstrated on the surface of every infusion. This histological argument merits special attention, because I do not see how it can possibly be answered. There can be no doubt that the minute molecules are formed first, and the bacteria, vibrios, and filaments, last. Supposing that the primary molecules, figured No. 1 (Fig. 6), enlarge to a certain point, No. 2, and then divide, how is it possible to explain the formation of elongated filaments at all? Surely the idea of their rapid multiplication by division is opposed to that of their power of elongating into bacteria and vibrios, whether by aggregation or growth from their extremities. It may frequently be seen that No. 3 is composed of molecules of exactly the same size as No. 2, which are floating loose,—a fact in favour of their coalescence rather than of their division, as then they would be reduced to half the size. It is more probable that although the smaller molecules may increase by imbibition of fluids, they have yet a constant tendency to aggregate together and melt into one another. No. 3 is not a proof of No. 2 dividing, but of two molecules coalescing; and when they unite, they form No. 4. Two or more of these uniting, form Nos. 5 and 6. When a similar process to this goes on in mineral bodies, as shewn by Mr Rainey,* it cannot suggest division but union (p. 41, Plate II. fig. 3; and this for the obvious reason, that the former would lead to disintegration, whereas, it can be seen in one case as in the other, that development is the result. In short, in the same manner as a tube is formed by a coalescence of cells, so is this

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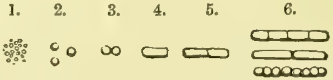
* Pouchet's Hétérogénie, p. 446.

† L. Gigot's Récherches expérimentales sur la Nature des Emanations marécageuses, Paris, 1859. Récherches sur l'Air des Maremmes de la Toscane, par M. E. Bechi. Comptes Rendus, tom. lii. p. 825.

‡ Comptes Rendus, tom. lvii. p. 558.

§ Nouvelles Expériences, p. 75.

Fig. 6.



Stages in the development of vibriones—800 *diameters linear.*

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* On the Mode of Formation of Shells, &c., 8vo, London, 1855, p. 12.

minute vibratile vibrio formed by the coalescence of molecules. It may be argued, however, that each molecule elongates itself —that is, No. 2 is converted into No. 4; this into Nos. 5 and 6; and that No. 3 are sporules or ova, caused by the disintegration of No. 6. But this view is opposed by the fact that Nos. 1, 2, and 3 are seen *before* Nos. 4, 5, and 6 are produced. Of this all have satisfied themselves who have examined animal and vegetable infusions; and the conclusion, therefore, cannot be resisted, that the vibrios are derived from the molecules, and not the molecules from the vibrios.

But it may also be supposed, that while some have the property of dividing, others are capable of elongating or aggregating; this view, however, is not only opposed to observation, but is at variance with all that we know of embryonic development in plants and animals. When a plant consists of a single structural element, such as a cell or a tube, it will, I think, be admitted that growth in the sense of increased bulk, and growth in the sense of multiplication of its parts by division, do not proceed at the same moment of time. Every plant and animal follows, in this respect, the same law. Nutrition is carried on up to a certain point of maturity, and then, and not till then, does generation, or the separation of parts to form new creatures, take place. When plants and animals are complex in their structure, one organ or segment may be growing, while another is disintegrating; but in elementary parts there is a period for growth and reparation, and a period for division or separation. Hence, it seems to me, I am correct in thinking that if the primary molecules on the surface of an infusion possess the property of dividing, they cannot also, at the same moment, possess the property of elongating and forming filaments. The one function is subversive of the other. While, then, a cell or a vibrio may possess the property of growth and division, these two functions must be exercised at different periods of time,—so that, in reference to the early stage of formation, if the molecules divide, bacteria, vibrios, and filaments could not be formed. A mass of vibrionic molecules is not a compound organism; it is a mere aggregation of similar simple elements. Each of these in passing through certain phases of development may be arrested, or reach maturity at various periods, so that we frequently see different forms present at one time; but that the same elementary forms and the same stages of growth should exhibit directly opposite functions, is surely not in accordance with physiological knowledge.

The conclusion we must arrive at therefore is, that the molecules seen on the surface of infusions out of which animalcules and fungi are produced, are not derived from the air.

Neither can they be supposed to pre-exist in the fluid, as then they would be readily seen, which they never are at the commencement. On this point nothing can be clearer than the microscopical evidence, so that it results from the facts and arguments which have been stated, that the more simple infusoria do not originate from cells or minute germs at all, whether in the atmosphere or in the fluid. This is the almost universal conviction of histologists who have carefully investigated the matter.

2. *Chemical Experiments which have been directed to destroy the supposed germs in the atmosphere, so as to prevent fermentation and putrefaction.*—Schutze, in 1837,* after heating an infusion to the boiling point, connected it with two of Liebig's bulbs, one containing sulphuric acid, and the other concentrated solution of potash. The air forced through these liquids he thought capable of destroying the atmospheric germs.

Schwann also, in 1837,† forced air, with the same view, through metallic tubes heated to redness ; and found, when so calcined, it occasionally prevented infusorial growth. He thought that oxygen alone was not the cause of fermentation, but some substance in the air capable of being destroyed by heat.

Schræder and Dusch, in 1859, filtered the air through cotton before bringing it in contact with organic fluids. They found that some did, and others did not, undergo putrefaction, and were induced to believe that the presence of oxygen, and the formation of an acid, were the cause of fermentation. Schræder afterwards found that the yolk of an egg, milk, and the juice of meat without water, putrefied in air filtered through cotton, and supposed it to contain an active substance, the nature of which was unknown. ‡

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* Poggendorf's Annalen, 1837, p. 41 ; and Edinburgh New Philosophical Journal, 1837.

† Poggendorf's Annalen, 1837, p. 184.

‡ Quoted by Pasteur, *opus cit.*, p. 16.

The experiments of Schutze, Schwann, Schræder, and Dusch have been frequently repeated without preventing the growth of fungi.*

Again, it is almost universally considered that the heat of boiling water or cold at zero will destroy all kinds of animal and vegetable life. Indeed, to imagine that the minute molecules or vibrios of which we have been speaking, or small ova and sporules consisting of oleo-albuminous matter without any envelope, would remain in boiling water for hours and retain their vitality, must be regarded as a violent assumption. Three or four minutes' boiling of a hen's egg not only kills it, but converts its whole substance into a hard mass. There is no seed known which, when taken out of its indurated shell or case, is capable of germinating after being boiled for a short time.† Yet nothing is more certain than that long ebullition of various infusions has wholly failed to prevent the formation in them of animal and vegetable growths.

As, therefore, neither calcined air, sulphuric acid, liquor potassæ, gun-cotton, or a boiling temperature have failed to prevent the production of infusoria, or destroy the supposed germs in the air or infusion, I determined, in 1863, to try the effects of all these destructive agents, with the exception of the first, at once, and with the greatest possible care.

On the 17th and 18th of October 1864, and on the 3rd and 13th of October 1865, I performed the following experiments in my laboratory, with the assistance of Dr Argyll Robertson :—

Decoctions of liquorice root, of tea, and of hay were kept at the boiling temperature in a porcelain basin, over a gas flame. Flasks filled with and inverted in the boiling fluid had air pumped into them to the extent of three-fourths of their volume which had passed through (1st) a U-shaped tube containing liquor potassæ; (2d) a hollow glass ball containing gun-cotton; (3d) Liebig bulbs, containing sulphuric acid; and (4th) another U-shaped tube with sulphuric acid. All the bent tubes were filled with fragments of pumice-stone to break up the air, so as to prevent the possibility of any germs passing through in the centre of bubbles. The bent glass tube leading from the last U-shaped tube, filled with sulphuric acid and pumice-stone, was also filled with the acid, so as to destroy any germs that might be supposed to adhere to the interior. After the air so prepared had entered the flask, corks, which had been for some time boiled in the infusion, were by means of iron forceps inserted in the necks of the flasks, and the entrance of fresh air prevented. Further, on removing the flask from the boiling infusion, the cork and neck were hermetically closed by plunging them into melted sealing-wax. At the same time bottles or flasks containing the same infusion, but having a similar proportion of ordinary air, were sealed or corked up, so as to be contrasted with the influence of the prepared air.

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* See Pasteur, *opus cit.*, pp. 34, 35. Pouchet's Hétérogénie, pp. 252, *et seq.*

† See some conclusive experiments recently performed on this subject by Meunier. Comptes Rendus, tom. lxii. p. 992. See also Pouchet's Experiments on the Seeds of Medicago from Brazil. Comptes Rendus, tom. lxii. p. 941.

In another series of experiments, on the 14th of October 1867, with Dr Rutherford, stoppered bottles were used, it having been suggested that sporules or germs might have been concealed in the corks formerly employed although they had been well boiled.

The results were that the infusions in all the flasks in contact with ordinary air were rendered turbid, or covered with fungi in from six to twelve days ; whereas all the infusions which were exposed to the prepared air also became turbid and contained fungi, but at periods varying from four to nine months. When the fluid was examined microscopically, bacteria and vibriones were always found. It was also found that rarified air delayed the appearance of these infusoria and of turbidity of the fluid.

It having been asserted by M. Pasteur* that passing air through bent tubes, by hindering the access of germs and allowing them to be deposited on the sides of the glass, prevented the growth of infusoria, twelve bottles were prepared on the 4th and 11th January 1868, four of which contained an infusion of dulcamara, another four a decoction of putrid meat, and a third four, yeast water. The bottles were plunged into, and filled with, the infusion when boiling, inverted in it, and allowed to get cold. The air was pumped gently through a bent tube, five feet in length, having fourteen sharp bends, each four inches long, into three bottles of each series, and ordinary air was admitted to the fourth. The result was, that the fluids in all soon became turbid, so that bent tubes appear to intercept none of the supposed germs. They only delay the result.

* Comptes Rendus, tom. i. p. 306.

In the numerous experiments made by Dr M'Kendrick in 1870, 1871, and 1872, it was found that if the fluid be introduced into a flask, boiled, the neck drawn out, bent so as to form numerous acute angles, and the fluid again boiled, it will remain free from turbidity, or the appearance of bacteria or vibriones for many months, but ultimately the change occurs. The bendings of the tube appear to delay the occurrence of putrefactive changes, but not entirely to prevent it. Moreover, the same effect of delay may be produced by simply having the neck of the tube drawn out to a length of twenty-four or thirty-six inches, without any bend whatever, or by inverting the flask so that the long neck hangs downwards, the atmospheric pressure preventing the escape of the fluid from the flask.

These experiments, on the whole, appear to me to be totally adverse to the atmospheric germ theory, and to indicate that the production or non-production of infusoria depends, for the most part, on the temperature, chemical constitution, density, and other physical properties of the air, rather than on living organisms there, which are developed in the fluid. Still, in every series of experiments, there are one or two exceptions. This has also been observed by Pasteur in most of his experiments, and he attributes them to some currents or limited portions of air being rich in germs, whilst others are free from them.* But that this explanation applies to my laboratory, in which all the experiments described were made, is not probable.

It is now admitted by M. Pasteur that the boiling temperature, that is 100° centigrade, does not prevent the growth of the supposed germs in the atmosphere ; but instead of considering this fact hostile to his theory, he concludes from it that the germs have the power of resisting that amount of heat, and of being most tenacious of life ; but he says, 130° centigrade always destroys their vitality. M. Pouchet, however, has shewn that the air, and the organic matter placed in boiling water, will germinate after they have been exposed to a heat of even 150° centigrade, and he says it may be raised to 200° centigrade, and yet animalcules and fungi will develop themselves.† Dr Bastian has found that even after exposing flasks containing organic fluids and hermetically sealed while boiling, to a temperature of 300° centigrade for several hours, animal and vegetable microscopic organisms were found in the fluid.*

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* Comptes Rendus, tom. li. pp. 350, 351.

† Ibid. tom. l. p. 1015.

In the same manner, air and infusions exposed to intense cold still produce animalcules, but, according to Pasteur, not so readily. Twenty flasks containing boiled infusions, and from which the air was expelled, were opened by him with excessive precaution on the Mer de Glace at Montanvert on the Jura. Notwithstanding the purity and extreme coldness of the air, infusoria appeared in five of his flasks.

As an illustration of the manner in which the controversy on this subject has been carried on in the Academy of Sciences in Paris, I may give a short account of that portion of it referring to the Glacier experiments. M.M. Pouchet, Jolly, and Musset opened eight similar flasks used by M. Pasteur at Montanvert, on the Glacier of the Maladetta, in the Spanish Pyrenees, 9000 feet above the sea, and 3000 feet higher than that of Montanvert, using all the precautions required by M. Pasteur. In addition, before cutting off the ends of their hermetically sealed tubes with a file, previously heated by a lamp, they held the flasks above their heads. Notwithstanding, infusoria appeared in all the infusions a few days afterwards.†

To this communication, presented to the Academy, Sept. 21, 1863, M. Pasteur replies, Nov. 2,‡ saying that he is rejoiced that his learned adversaries have gone to such an altitude to repeat his experiments; but observes that they did not take the necessary precautions. They only had eight flasks, whereas he had twenty; they shook their flasks before opening them, which he took care not to do; and they had the imprudence to use a file, instead of a pair of pincers with long branches, heated in the flame of a lamp. He says that the thumb and fingers holding the file were too near the opening into the flask, and may have conveyed germs there, especially as they were not passed through the flame, as the file was.§ He defies them, if they take sufficient precautions, to obtain infusoria in all their flasks.||

MM. Jolly and Musset accept the defiance of M. Pasteur,

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* Bastian: The Modes of Origin of Lowest Organisms. 1871.

† Comptes Rendus, tom. lvii. p. 558.

‡ Ibid. p. 724.

§ Ibid. p. 725.

|| Ibid. p. 726.

Nov. 16,* and, in fact, on the 13th June following, they send a memoir to the Academy, stating that they had returned to the Maladetta, this time with twenty-two flasks—that is two more than were used by M. Pasteur—fulfilled all his conditions, not forgetting the pincers with long branches, properly heated, and found that infusoria appeared in every flask without exception in four days;† and so ended this part of the controversy.

Numerous other important questions have been debated before the Academy. Among these are the changes which take place in the air confined in the flasks, founded on numerous analyses;‡ the observations of Jolly and Musset with regard to vibrios living in distilled water;§ the statement by M. Pasteur that neither free oxygen nor atmospheric air are necessary for the growth of infusoria,|| and that they will develop themselves in carbonic acid gas only. Lastly, the same chemist declares that, notwithstanding his often declared opinion that ferments are living beings and not dead matter, he can produce fermentation with the ashes of yeast.¶ Some of these statements are confirmed by Donné,** who found that hens' eggs became putrid without the formation of vibrios or other infusoria. This observation, while it might serve to prove that atmospheric air passing through the egg-shell separated the germs by filtration, is wholly opposed to the idea that putrefaction is necessarily caused by such germs.

The only conclusion I can draw from the numerous contradictory and ingenious communications presented to the Academy of Sciences on this matter is, that not the slightest proof is given by the chemists, with M. Pasteur at their head, that fermentation and putrefaction are necessarily dependent on living germs existing in the atmosphere. They rather tend to shew that these are phenomena of a chemical nature, as was ably maintained by Liebig.†† Did we, indeed, confine our reading to the papers of M. Pasteur—that is, to one side of the case—we could easily persuade ourselves of his correctness;‡‡

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[*] Comptes Rendus, tom. lvii. pp. 842-845.

[†] Ibid. lvi. p. 1122.

[‡] Ibid. pp. 734-739.

[§] Ibid. lv. p. 491.

[||] Ibid. li. pp. 345, 346; liv. p. 267; lvi. p. 1191.

[¶] Ibid. lvi. pp. 418, 419.

[**] Ibid. lviii. pp. 951, 952; lxv. p. 602.

[††] Letters on Chemistry, letters xviii. and xix.

[‡‡] This is what unfortunately seems to have been done by the Commission of the Academy, which made a report on this subject, Feb. 20. 1865 (Comptes Rendus, tom. xl. p. 384). No histologist was on the Commission, which refused to enter

but every one of his experiments has been repeated by several independent investigators, who have shewn his imagined proofs as to the existence of atmospheric germs to be altogether erroneous. We may conclude, therefore, that living germs are not necessarily the cause of putrefaction and fermentation; neither is it necessary to believe that ferments are living at all—they may be dead. This, if not admitted, seems to be implied by Pasteur himself, who tells us he can now excite these processes, not by fresh yeast only, but by the ashes of yeast.* That they may be induced by dead organic matter which has been subjected to a direct temperature of 150° or 200° centigrade—a heat utterly incompatible with the existence of life—we have seen to have been proved by Pouchet, Jolly, Musset, and others.

The idea that these imaginary germs were the cause of putrefaction, of disease, of blights among vegetables, and other evils, originated with Kircher and the pathologists of the seventeenth century. It has been frequently revived, but always shewn to be erroneous. In 1852, cholera was supposed to be occasioned by a fungus that really existed in the dejections, but which Mr Busk pointed out was the *uredo segetum* of diseased wheat, which entered the body in the form of bread. Certain well-known parasitic diseases are spread by contact, such as scabies, which, as it depends upon an insect burrowing in the skin, may be understood to crawl from one person to another. I succeeded, in 1841, in proving that Favus might be made to grow on diseased surfaces of otherwise healthy persons; but many of our unquestionably infectious diseases, such as smallpox, scarlatina, measles, and typhus, have no such origin. It has been attempted to be shewn, indeed, by Lemaire,† that in the condensed vapours of hospitals and other putrid localities, vibrios may be found; but that vibrios are the cause of these various diseases, is not only not proved, but from what has been stated, is highly improbable. We have previously alluded to the molecules which, according to some, convey some of these poisons. (See p. 104.)

What, then, it may be asked, is the origin of the infusoria,

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upon any kind of microscopical inquiry; Messrs Pouchet, Jolly, and Musset, under such circumstances, very properly took no part in the investigation, which, consequently, was altogether one-sided, and of no scientific value.

* Comptes Rendus, tom. lvi. pp. 418, 419.

† Ibid. tom. lix. pp. 317-428.

vegetable and animal, that we find in organic fluids during fermentation and putrefaction? In answer to this question, I say they originate in oleo-albuminous molecules, which are formed in organic fluids, and which, floating to the surface, form the pellicle or proligerous matter. There, under the influence of certain conditions, such as temperature, light, chemical exchanges, density, pressure, and composition of atmospheric air, and of the fluid, &c., the molecules, by their coalescence, produce the lower forms of vegetable and animal life.

Other researches may be referred to as confirming these conclusions, such as—

1. *The development of Botrytis Bassiana in Muscardine, a disease of silk worms.*—The true cause of this disease was first ascertained by Bassi in 1835, who shewed that it depended on the presence of a fungus which developed and multiplied within the body of the worm or moth, caused its death, and appeared through the skin in many places as a whitish growth. M. Guérin-Méneville* has observed the development of the fungus filaments from the blood corpuscles of the worm. A similar disease occurs in the house fly in autumn, and is said by Cohn to depend on a mould called *Empusa*, which also originates from the blood cells.†

2. *The development of Penicillium from milk globules.*—This was first described by Turpin in 1837.‡ When a drop of milk is examined after it has acquired an acid reaction, flakes of casein will be found along with bacteria and milk globules variously altered. These milk globules throw off buds from their margin, which grow into mycelium-like filaments, and soon the milk is covered with a whitish mildew, seen with the naked eye.

3. *The development of Bacteria within the laticiferous vessels of plants.*—M. Trecul, a distinguished French botanist, has found numerous minute bodies, of a globular or cylindrical form, some motionless, others shewing slight undulating movements, within the laticiferous vessels of *Apocynum cannabinum*, in the closed medullary cells of the *Ficus carica*, and in the fibre cells of the bark of various plants, such as *Asclepias cornuti*, the common elder, &c. &c.§ He believes these living bodies,

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* Comptes Rendus, tom., lvi., p. 574.

† Hedwigia, 1855, p. 59.

‡ Turpin, Ann. des Sc. Nat., 1837 (Zoologie), tom. viii., p. 349.

§ Comptes Rendus (1865), tom. lxi., pp. 158, 432, and 435.

to which he gives the name of *Amylobacteria*, are derived from metamorphosed starchy matter, hence their name.

4. *The occurrence of Bacteria, Fungi, &c., in the centre of the organs of dead animals or in the closed cavities of the body.*—Nothing is more common than to find these organisms in the centre of the brain, in the centre of the liver, even in the hepatic cells, in epithelium cells, or in any part of a dead or even a living body undergoing putrefaction. Berkeley has found a yellow mould within the cerebral cavity of golden pheasants.* Murie has seen fungus-growths within the abdomino-pleural membrane of a kittiwake gull, of a great white-crested cockatoo, and of a rough-legged buzzard.† Bacteria and fungi have often been found in eggs. Helmarecht found spores in the aqueous humour of the human eye.‡ Numerous other examples might be given, but enough has been brought forward to shew that foreign living organisms have originated in situations entirely removed from the air.

ABNORMAL REPRODUCTION.

This consists in the various alterations which may occur in the different stages of the generative functions, and include,—1st, Diseases which arrest or modify ovulation ; 2d, Diseases, nutritive or nervous, which impede fecundation, and occasion barrenness in the female, or impotence in the male ; 3d, Diseases of the embryo, causing various kinds of monsters, from arrest or excess of development in one or more of its parts. This last subject is now generally studied under the name of *teratology* (τέρας, *monster*), and has in recent times become a very extensive one. Congenital malformations of the fœtus were formerly considered as indicative of some misfortune,—as the effect of witchcraft, or as offsprings of the evil spirit. They are now not only recognised to originate in natural derangements of embryonal development, but the laws which govern such derangements have to a great extent been determined. From these it has become evident that monstrosities are not the result of chance, but are always induced by alterations in the known processes which regulate reproduction, and the evolution of the ovum and its contents. Hence in this, as in every other disordered condition, the real source of the abnormality is to be sought for, not only in the investigation of that condition itself, but in the knowledge, first, of the healthy or physiological state ; and secondly, of the manner in which it has become deranged. In all our inquiries, it must be apparent that disease is morbid physiology ; and such is the aspect in which we have endeavoured to place it before the reader.

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* Berkeley, Introduction to Cryptogamic Botany, p. 260.

† Murie, Report of British Association, 1871.

‡ Robin's "Végétaux Parasites," 1853, p. 370.

ON DEATH.

Death is the permanent cessation of those properties and functions which constitute life. In this wide sense, it must be apparent that the textures are continually dying, in the same manner that they are continually being generated. What we have described as the secondary digestion essentially consists in the removal of the particles of the body which have been worn out,—fulfilled their functions, and died. Thus, death is molecular, cellular, fibrous, or tubular, in proportion as these various organic elements become degenerated, and disappear to make way for others which enjoy activity or life, and in their turn die, enter into new chemical combinations, and are excreted like their predecessors. In the more common acceptation of the term, however, death may be considered as *partial* or *general.* Partial death of the animal body is caused by those diseases or injuries which produce mortification and ulceration in soft, and necrosis and caries in the hard parts, to a greater or less extent. Of this we have already spoken, and therefore need only treat of general death of the system. This has been variously considered as *natural* or *unnatural ;* by the former meaning death from old age or gradual decay, and by the latter, death from diseases or violence. In this latter case, death may be gradual or sudden, and be induced by a great variety of agents. It may be said, however, that all the modes of death are reducible to three, viz. : 1st, Death by syncope—that is, beginning at the heart ; 2d, Death by asphyxia, beginning at the lungs ; and 3d, Death by coma, beginning at the brain.

Death by syncope.—All causes which arrest the action of the heart occasion stoppage of the circulation ; a circumstance which interferes with the due performance of the vital functions ; and death is the consequence. It may occur through the nervous system, through feebleness of the muscular walls of the heart itself, or through loss of blood. As examples of the first method of causing syncope, may be cited concussion, or all sudden shocks to the system—as from violent blows or injuries, extensive lesions, violent mental emotions, a stroke of lightning, exposure to the sun (or *coup de soleil*), and certain poisons which, acting especially on nerves going to the heart, paralyse its rhythmical motions, as aconite, digitalis, &c. Syncope, from feebleness of the muscular walls is illustrated from the effects of long-continued violent exertion, starvation, and disease of its textures, especially that now recognised as fatty degeneration, one of the most common causes of sudden death. Lastly, excessive loss of blood, whether from direct external injury to a large vessel, sudden bursting of an internal vascular tumour or aneurism, disease of the coats of an artery or vein leading to sudden or to long-continued loss of blood, are among the frequent causes of syncope.

Death by asphyxia.—This is produced by all causes which interrupt the act of respiration, or the access of oxygen, so necessary for carrying on the nutritive functions, and has been previously referred to (p. 233). It is now ascertained that mere obstruction of air does not immediately act upon the heart, which not only continues to contract for a time, but even sends venous blood through the arterial system. From the numerous investigations which have been made to determine in what manner the vital actions are arrested in asphyxia, it would appear that at first non-aërated or venous blood passes freely through the lungs to the heart, from whence it goes to all parts of the system. It operates on the brain, however, as a poison, rapidly suspending the sensorial functions. The capillaries of the lung next refuse to transmit non-oxygenated blood, in consequence of which it is not returned to the right side of the heart, and thus the vital actions cease. These effects are produced with greater or less rapidity, according as the occlusion of air is more perfect, as in cases of drowning and strangulation. In diseases of the heart and lungs, the same results are produced more slowly. The only poisons which operate upon the lungs directly causing asphyxia are certain so-called poisonous gases, such as carbonic acid gas, the fatal effects of which, however, are not so much to be ascribed to any noxious properties it possesses as to the absence of free oxygen.

Death by coma.—This is caused by all circumstances which suspend the sensorial functions by first operating on the brain.

We observe it produced from the long-continued action of cold, from the influence of narcotic poisons, especially opium and chloroform, and from such injuries of the brain, from without or within, as are not necessarily connected with shock. If a violent blow be given to the head of an animal, it may be observed to suffer from shock or syncope ; the heart flutters, and the pulse is weak. But if it recover from this, the heart's action may be restored, while sensation is suspended, and it dies comatose. If shock be avoided during the operation, the brain of an animal may be removed, producing coma or stupefaction, which will ultimately kill, although for some time the circulation and respiration continue. In apoplexies, fevers, and other diseases, similar effects are observable.

It should not be overlooked that death in many cases is produced by a conjunction, or by the rapidly-following results of two or all three of these modes. Thus, chloroform may kill from the conjoined stupefying action on the brain, as well as from difficulty of respiration. Coma, from pressure on the brain, may, by influencing the *medulla oblongata*, affect the pneumo-gastric nerves, which send branches to the heart and lungs. In this case, death is the most rapid—occurring in all three ways. Hence the humane effort of the hangman not only to produce strangulation, but by dislocation of the bones of the neck, to crush the upper part of the spinal cord.

The preceding observations evidently indicate that, in our endeavours to produce recovery from either of these states, much will depend upon the correct information we derive as to the causes producing them. In syncope, our efforts will be directed to restore the action of the heart by stimuli, a proper position, checking hæmorrhage, &c. ; in asphyxia, to reproduce respiration ; and in coma, to remove any cause which, by pressure on the brain from without or within, interferes with its functions.

PART III.

PRACTICAL PHYSIOLOGY.

By the term "practical," is not understood giving lectures on practical as distinguished from theoretical subjects. What I understand by it is causing the student himself to perform with appropriate instruments the necessary investigations, so that he may learn the art of observation, and obtain the necessary manual dexterity for arriving at exact results. Thus, practical chemical physiology consists not in being shewn by the teacher how to analyse the various fluids and solids of the animal frame, but in his doing this himself. Practical histological physiology is not merely examining objects and preparations, but in causing the student to manipulate the microscope, demonstrate for himself, and describe what he sees. Practical experimental physiology, in like manner, consists not only in witnessing, but taking part in, the performance of experiments on animals, with all the modern instruments of precision that science in recent times has placed in our hands.

PRACTICAL PHYSIOLOGICAL CHEMISTRY.

Practical physiological chemistry includes an examination of the solids and fluids of the body. The physical properties of the substance, such as form, colour, hardness, specific gravity,

&c., must first be accurately observed. It is then subjected to chemical analysis, either quantitative or qualitative, and a systematic mode of procedure followed.

I. *GENERAL QUALITATIVE EXAMINATION OF AN ANIMAL FLUID.*

The examination should be made in the following order :—

1. *Reaction to test paper.*—The tests used are blue litmus paper, which becomes red when dipped in an acid fluid, and red litmus, which turns blue, or yellow turmeric paper, which becomes brown when immersed in an alkaline fluid. An acid reaction of a liquid indicates the presence of free acids or of acid salts, whereas an alkaline reaction is produced by free alkalies, alkaline phosphates, or carbonates. If an alkaline reaction disappear on gently heating the paper over the flame of a spirit lamp, it informs us that the alkali is volatile ; if it remain, the alkali is fixed.

2. *Filter, or strain.*—A fine, white, thin blotting paper is the best filtering medium for ordinary purposes. When the liquid passes through the paper turbid, it should be returned once or twice to the filter till it comes through clear. The precipitate should be preserved by being scraped off with a spatula of ivory, platinum, or steel, or it may be washed off with a gentle stream of water from an ordinary wash bottle. Sometimes it is necessary to strain through one or several folds of muslin or cotton.

3. *Heat a portion of the filtrate.*—This should be done in a test tube over a spirit lamp. If no precipitate is formed, albumin is absent. If a precipitate appear, it may be albumin or phosphates. Add a few drops of dilute hydrochloric or nitric acid. If the precipitate disappear, *albumin* is absent (p. 8), but *earthy phosphates* may be there (p. 28). These must be looked for and isolated by special tests.

4. *Add to the fluid a solution of Ferrocyanide of Potassium.*—If there be no precipitate, casein and globulin are absent. If a precipitate fall, take a fresh portion of fluid and divide into two parts. To one add a solution of chloride of calcium and apply heat. A precipitate indicates *casein* (p. 9). Carefully neutralise the other portion,—if acid, with an alkali, if alkaline, with a few drops of acid,—and observe whether a precipitate be

formed at the point of neutralisation. If a precipitate appear, *globulin* is present (p. 10).

5. *To a portion of the liquid add acetic acid.*—A precipitate may be formed. If so, it is chondrin, mucus, or pyin. To a portion add a solution of common alum or sulphate of copper. If a precipitate fall, soluble in excess of the reagent, *chondrin* is present (p. 11). To another part add a solution of corrosive sublimate, and if there be a precipitate, we have pyin, or mucin (p. 11). Neutral acetate of lead distinguishes the two, giving a copious precipitate with *pyin* and a very slight turbidity, or none at all, with *mucin.*

6. *Evaporate a few ounces of the liquid to one-sixth of its bulk.*—If a jelly form on cooling, we have *chondrin*, or *gelatin* (p. 10). For the mode of distinguishing chondrin see last paragraph. If there be a precipitate, it may be *urates*, *phosphates*, *sulphates*, *allantoin*, *tyrosin*, *hippurate of calcium*, or *benzoic acid*. These must be examined microscopically, and by special tests, to be afterwards described.

7. *Evaporate a few ounces to a syrup, and allow it to stand for forty-eight hours.*—If crystals form, allow the fluid to stand as long as they increase. Such crystals may be *creatin* (p. 18), *creatinin* (p. 18), *leucin* (p. 17), *allantoin* (p. 16), *taurin* (p. 16), *sarcin* (p. 16), *inosite* (p. 27), *hippurates of potash or soda* (p. 15), *sodium chloride*, and other salts (p. 28). The next point to determine is, do the crystals consist of organic or inorganic matter. Heat a small portion on a clean bit of platinum foil. If it blacken when strongly heated, organic matter is present. If a whitish-coloured residue be left, after heating strongly, it consists of inorganic matter ; and the probability is we have an organic acid united with an inorganic base. If the crystals consist solely of organic matter, they must be examined by processes of organic analysis for nitrogen, sulphur, and phosphorus, and their chemical composition determined. The tests for these substances will be given when we treat of special fluids and solids.

8. *Separate the crystals from the syrup, and exhaust the residue with alcohol of specific gravity* 0·833.—Treat as follows :

DIVIDE ALCOHOLIC SOLUTION INTO SIX PORTIONS.

1. Concentrate, dilute with water, place a few drops on a porcelain plate, and add a drop of nitric acid. Play of colours indicates	*Bile pigment* (p. 32).

2. Concentrate, dilute with water, place in a test tube, add ½ bulk of syrup, then allow a drop or two of sulphuric acid to flow down side of test tube. Play of colours at junction of fluid and syrup indicates *Bile acids* (p. 12).

3. Evaporate to dryness, dissolve in water. Apply the tests for sugar according to methods to be afterwards described . . . . *Sugar* (p. 25).

4. Evaporate to a small bulk, add nitric acid; laminar crystals of nitrate of urea separate out—indicating *Urea* (p. 14).

5. Mix with a very strong solution of chloride of zinc. A crystalline precipitate indicates . . . *Creatin and Creatinin* (p. 18).

6. Heat with oxide of zinc, filter while hot, and evaporate a drop on a glass slide. Club-shaped crystals of lactate of zinc indicate . . . . *Lactic Acid* (p. 27).

9. *Evaporate part of original fluid to dryness, pound the residue in a mortar, and exhaust with ether.*—This etherial extract containing fats in solution, is evaporated and further examined.

10. *Incineration.*—The residue insoluble in ether is incinerated in a platinum capsule, and the ash examined by the ordinary methods of inorganic analysis.

General Conclusion.—By these ten processes we ascertain whether the fluid be acid, alkaline, or neutral, and whether it contain albuminates, albuminoids, or albuminous derivatives. We also obtain a knowledge of the presence of fatty matters or mineral principles.

II. *QUALITATIVE AND QUANTITATIVE ANALYSIS OF SPECIAL ANIMAL FLUIDS.*

The fluids we specially examine are—(1.) The *blood;* (2.) The *chyle;* (3.) The *lymph;* (4.) The *saliva;* (5.) The *gastric juice;* (6.) The *pancreatic juice;* (7.) The *bile;* (8.) The *urine;* (9.) The *sweat.* Under this head we may also describe the analysis of (10.) The *fæces.*

Analysis of Blood.

For the chemical constitution of the blood, see pp. 239, 240. The analysis is conducted in the following manner. The reaction is usually slightly alkaline.

1. *Water.*—Weigh out a certain definite quantity, evaporate in a porcelain basin over a water bath, and dry the residue in a hot air chamber, at a temperature between 120° and 130° C. Weigh again. The loss in weight will represent the water.

2. *Fibrin.*—Receive an ounce or two of the blood into a glass vessel as it flows from a vein, stir it up for ten minutes with a glass rod or twig of birch till the fibrin is separated. The blood, with the fibrin, is then weighed, and strained through muslin to separate the fibrin, which is well washed with water, dried, and boiled with alcohol and ether to free it from fat. The alcohol and ether are driven off by evaporation, the fibrin is dried at 120° C., and again weighed. The weight indicates the amount of fibrin in the portion of blood examined.

3. *Albumin and substances coagulated by heat.*—A few ounces by weight of blood are acidulated with acetic acid, and added drop by drop to boiling water. The aqueous liquid is then poured upon a carefully weighed filter, and the coagulum separated. The coagulum is then washed on the filter with boiling water, and dried at 120° C. It is then weighed, the weight of the fibrin deducted, and the balance represents albumin, and a small amount of certain other substances coagulable by heat.

4. *Fat.*—A weighed quantity of blood is dried at 100° C., and treated with ether. The etherial solution is filtered into a platinum capsule, in which it is slowly evaporated, and the residue dried at 100°. The weight of residue gives the amount of fatty matter.

5. *Extractive matter and mineral constituents.*—The filtrate obtained in the estimation of the albumin is evaporated on a water bath, and the residue dried and weighed. It is then burnt at as low a temperature as possible. An ash is left, which consists of mineral constituents. The weight of this ash is deducted from the weight of the dried residue, and the difference is the extractive matter. The mineral matter may also be obtained by the process of dialysis (p. 118).

6. *Mineral matter.*—A quantity of the blood is weighed, mixed with ignited carbonate of soda, dried and burnt at as low a temperature as possible. The residue is the ash. The incineration must be done with great care, as the chlorides of potassium and sodium volatilise at a high temperature ; phosphates may be decomposed, and sulphates reduced to sulphides. The ash is then treated as follows :

DIVIDE INTO TWO PARTS.

First portion—Treat with dilute nitric acid; add nitrate of silver to precipitate the chlorine as chloride of silver . . . . *Chlorides.*

Second portion—Treat with dilute hydrochloric acid. Divide into three portions.

1. Add chloride of barium to precipitate sulphuric cid as sulphate of barium . . . *Sulphuric acid.*
2. Mix with ammonia and a little acetic acid—
    - (1.) Add oxalate of ammonia to throw down lime as oxalate of lime . . . *Lime.*
    - (2.) Add excess of ammonia to throw down all the magnesia and part of the phosphoric acid . . . . *Magnesia and phosphoric acid.*
    - (3.) Add sulphate of magnesia to throw down the rest of the phosphoric acid . . *Phosphoric acid.*
3. Add a little oxalic acid to throw down the lime, and also a few drops of ammonia, and phosphate of ammonia, to throw down the magnesia. Filter. Dry the residue, and dissolve in hydrochloric acid. Add tetrachloride of platinum, which throws down all the potassium as a yellow crystalline precipitate. In the fluid, on evaporation, will be found the sodium salt . *Potassium and Sodium.*

7. *Serum and coagulum.*—A certain amount of blood is allowed to stand in a vessel till all the clot has separated. The clot is then carefully detached by a needle or sharp knife from the side of the vessel. The blood is weighed, and after the clot has contracted as much as possible, the serum is poured off. The clot is dried by means of blotting paper and again weighed. If we deduct the weight of the clot from the total weight of the blood, we find the proportion of serum.

8. *The colouring matter of the blood, Hæmoglobin, Hæmataglobin, or Hæmatocrystallin.*—(See p. 31, and Plate I. figs. 20 and 22.) Take a few ounces of blood, beat with a twig of birch for a quarter of an hour to separate the fibrin, strain through a linen cloth along with a mixture consisting of one volume of a saturated solution of sodium chloride and nine volumes of distilled water. A precipitate is formed, which is shaken up with a little water and from four to ten times its volume of ether.

The ether is drawn off with a pipette after several hours, and is found to contain cholestrin. An aqueous solution of the residue is now brought to a low temperature, and a pulpy mass forms consisting of crystals of hæmoglobin.

9. *Estimation of Iron.*—This may be readily done by burning the hæmoglobin obtained by the process just described. When hæmoglobin is burnt, a small residue of ferric oxide is left, from the weight of which the amount of iron is then calculated (every 100 parts of ferric oxide containing 70 parts of iron).

10. *The optical properties of Hæmoglobin.*—These may now be examined according to the method and optical principles described at pp. 32 and 138. For this purpose we require an instrument termed a *spectroscope*, of which there are two principal varieties, the ordinary spectroscope and the micro-spectroscope. When there is a large quantity of blood available, as in most physiological experiments, the ordinary spectroscope should be employed, but when only a drop or two of blood can be obtained, we use a spectrum apparatus fitted to a microscope. The construction of a spectroscope depends on the optical principle that when a ray of sunlight, or a ray of white light from an artificial source, passes through a prism it splits up into a number of individual coloured rays, in the following order, running from left to right—red, orange, yellow, green, blue, indigo, purple, and violet (p. 138). The ordinary instrument consists essentially of three parts : 1st, a tube having at the end an adjustable slit for admitting the light ; 2d, a prism made of flint glass, or a triangular glass bottle filled with Disulphide of Carbon ; and 3d, a magnifying glass or telescope for increasing the apparent size of the spectrum. The tube of the telescope must be placed in a different direction to the tube carrying the slit, because the coloured rays forming the spectrum form an angle with the incident rays as they enter the prism.* When a thin layer of a liquid, such as arterial blood (which contains oxy-hæmoglobin, p. 32), is placed in front of the slit, the colouring matter intercepts certain coloured rays of the spectrum, so that two dark bands are seen between the yellow and green of the ordinary spectrum. For this experiment the blood must be greatly diluted with water and a small test tube, or still better, a vessel having parallel sides of thin glass, filled with the solution, is placed before the slit. To increase the amount of light, it

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* Schellen, Spectrum Analysis. London, 1872.

may be concentrated on the slit by means of a powerful bull's-eye condenser.

The microspectroscope of Sorby and Browning is a spectrum arrangement which can be applied to any microscope by fixing it in the place of the ordinary eyepiece, so that spectroscopic investigation of an object can be pursued without any change in the manner of using the instrument. By means of this instrument the two absorption bands of arterial, and the single one of venous blood, can be readily recognised.

Recently, W. Preyer* has applied the method of spectrum analysis to the determination of the quantity of hæmoglobin. "The determination depends upon the fact that a concentrated solution of hæmoglobin in a layer of certain thickness is opaque, even in strong illumination, to all rays except the red, whereas less concentrated solutions in a layer of the same thickness give passage to other rays besides the red and orange, and especially to a portion of the green. If, therefore, a measured quantity of blood placed before the slit of the spectral apparatus be diluted with water till green light appears in the spectrum, and if the proportion of hæmoglobin in a solution which transmits the green under exactly similar circumstances has once for all been determined, it is easy to estimate the percentage of hæmoglobin in the blood under examination."†

11. *Effect of passing a stream of carbon monoxide through blood.*—When a stream of carbon monoxide is passed for some time through blood, and a little of this blood is examined by the spectroscope, the two absorption bands of oxy-hæmoglobin will be seen. Hoppe-Seyler of Strasburg has pointed out that these absorption bands do not disappear and give place to a single band on the addition of sulphide of ammonium even after several days, and he proposes this unalterability of blood containing carbon monoxide by ammonium sulphide as a test for the presence of this gas in the blood. ‡

12. *Detection of blood stains by the formation of Hæmin crystals.* §—Sprinkle a few grains of common salt on the stain. After a few minutes add a few drops of glacial acetic acid.

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* Ann. Chem. Pharm. cxl., p. 187.

† Watt's Dictionary of Chemistry. Supplement, p. 353.

‡ Hoppe-Seyler, Zeitschrift Anal. Chem. iii. 439. Jahresb. 1865. p. 745.

§ Brücke, Jahresb. 1857. P. 609.

Scrape off as much matter as possible from the stain, and place it on a glass-slide. If necessary to moisten still more, add another drop or two of glacial acetic acid. Then carefully put on a thin covering glass, and lay the slide aside for two hours in a moderately warm place, say four feet from an ordinary fire. At the end of this time, examine with a power of 250 diameters and the black crystals of hæmin will be found. (Plate I. figs. 19 and 21.)

13. *Guiacum test for blood.*—Another test for blood is given by tincture of guiacum. A drop of freshly prepared tincture is placed on a bit of white blotting-paper. A drop of any solution suspected of containing blood is added, and afterwards a drop or two of hydrogen dioxide (H_2O_2). If blood be present, the stain on the blotting-paper soon turns from green to blue. This, however, is not a test to be absolutely depended on, because saliva, gum arabic, citrate of iron, &c., give the same reaction. As a negative test, however, it is valuable, because if the blue colour be not obtained, blood is certainly not present.*

14. *Gases of the blood.*—The method of L. Meyer for determining the gases of the blood is as follows :—The blood is diluted with ten times its bulk of water, and the gases are collected by boiling the liquid in vacuo at a gentle heat. The *free* gases are thus obtained. A few crystals of tartaric acid are then added, the blood is again boiled, and the *combined* gas is liberated. The gases of the blood consist of oxygen, nitrogen, and carbonic acid. They are introduced into a special apparatus for the analysis of gases.† The carbonic acid is absorbed by caustic potash, and the amount thus determined. The amount of oxygen is found by exploding the mixture with an excess of hydrogen, and one-third of the total amount of contraction caused by the explosion is the quantity of oxygen present. To ascertain the nitrogen, all the other gases must be removed, and the residue consists of nitrogen. The gases may also be collected by means of an air pump, of which the best form for this purpose is the mercurial air pump of Sprengel.‡

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* Van Deen, Zeitschrift Anal. Chem. ii., p. 459. Taylor, Guy's Hospital Reports. 1868.

† For details as to analysis of gases, see Watt's Dictionary of Chemistry, vol. i. p. 268.

‡ Quicksilber—Luftpumpen; Müller—Pouillet's Lehrbuch der Physik. I. Bd. s. 211; II. Bd. s. 941. Also Dr Wüllner's Lehrbuch der Experimentalphysik. I. Bd. p. 365.

The serum of blood has also been found to contain sugar, urea, uric acid, creatine, creatinine, hippuric acid, hypoxanthin, leucin, and tyrosin, which substances exist only occasionally in very small quantity, and are difficult to isolate.

ANALYSIS OF CHYLE.

This fluid must be obtained from the thoracic duct of an animal killed during digestion. It is an opalescent, milky liquid, having a saline taste and a very weak alkaline reaction. The specific gravity varies from 1012 to 1025. It may be analysed by pursuing the same method described for the blood. Numerous analyses made by Pelouge, Frémy, Rees, Simon, and Nasse vary as to the relative proportions of its constituents.

ANALYSIS OF LYMPH.

When obtained fresh from the lymphatic vessels, its reaction is usually alkaline. It soon coagulates, forming a jelly-like coagulum. The coagulum will be found to consist of a substance identical with fibrin. The fluid contains albumin, which may be readily separated by dropping into boiling water. A small amount of fat may be found by shaking up with ether. A very small amount of extractive matter may be taken up with alcohol. The salts are separated either by obtaining the ash, or by means of dialysis. They are found to consist of sodium chloride, alkaline carbonates, salts of ammonia, sulphates, and phosphates.

ANALYSIS OF SALIVA.

This may be obtained by introducing a small silver canula into either Stenson's or Wharton's duct, and may be examined according to the method already detailed (p. 445). The reaction is alkaline. Evaporation will yield the amount of solid residue. On allowing saliva to stand for some time in a beaker, it becomes opalescent or turbid, and bubbles of gas form on the surface. This is due to a deposition of calcium carbonate and the escape of carbonic acid. When a drop of saliva is placed on a porcelain lid, and a drop of Ferric chloride added, a blood red or yellowish red colour is obtained owing to the presence in saliva of sulphocyanide of potassium.

Separation of ptyalin.—Dilute the saliva with dilute phosphoric acid, add lime water, and thus obtain a precipitate containing phosphate of lime, ptyalin, and a small amount of albumin. Shake up with distilled water. The ptyalin is dissolved and separated from the other two substances. This solution of ptyalin may be concentrated by evaporation, and its action on starch observed.

ANALYSIS OF GASTRIC JUICE.

This fluid may be collected by making in a dog a gastric fistula, into which a silver or gold canula, having a stop-cock, is introduced. The gastric juice is transparent, colourless, or slightly yellowish. It has a sourish odour. When obtained during fasting it is neutral or slightly alkaline, consisting chiefly of mucus, but during the ingestion of food it is strongly acid (p. 203).

Water.—This may be calculated by evaporating a given weight of gastric juice and weighing the residue. Deduct this weight from that of the gastric juice, and the difference yields the weight of water.

Preparation of pepsin.—Add alcohol, which precipitates the pepsin. Evaporate and pepsin is obtained, the properties of which should be examined as follows:—Dissolve in warm water. Divide into five portions, and treat as follows:

1. Add solution of corrosive sublimate.	*Dense precipitate of pepsin.*
2. Add protochloride of tin.	
3. Add basic acetate of lead.	
4. Add tannic acid.	

5. Add a few drops of hydrochloric or lactic acids, then several pieces of minced meat, and lay aside in a warm place (100° F.) for four hours. *The meat will then be found soft, whitish in colour, and partially digested.*

Acid of the juice.—Great differences of opinion have prevailed as to this point, Bernard * and others asserting that no hydrochloric acid is present, but only lactic acid; while Bidder and Schmidt † declare they have found free hydrochloric acid. Gastric juice will always be found to give a precipitate with nitrate of silver or oxalic acid. It is probable that sometimes one sometimes the other acid is present, while occasionally both may be there.

Ash of the juice.—When examined in the usual way, sodium and calcium chlorides; potassium, sodium, and calcium sulphates; and calcium carbonate and phosphate, will usually be found.

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* Bernard, Leçons de Physiologie Expérimentale. Paris, 1856. ii.

† Bidder und Schmidt, Die Verdauungssäfte und der Stoffwechsel. Mittau und Leipsig, 1852.

ANALYSIS OF PANCREATIC JUICE.

This fluid may be obtained in sufficient quantity for analysis by cutting the duct, inserting a canula, and collecting the juice in a caouchouc bag. It is clear, viscid, and has an alkaline reaction (p. 203). The amount of solid matter may be ascertained by evaporating a known quantity, drying carefully in a hot-air chamber over sulphuric acid and under the receiver of an air pump, and weighing the residue.

Preparation of pancreatin.—Add to the juice its own bulk of alcohol. A white flaky precipitate falls. Filter, dry carefully, and dissolve the filtrate in water. This is probably a solution of pancreatin along with a protein substance allied to casein. Danilewsky* has tried to shew that in the pancreatic juice we have three ferments: one which acts on starch and albumin and fats; a second, which acts on starch and albumin but not on fats; and a third, which acts on starch but not on albumin.

ANALYSIS OF BILE.

Ox-bile is usually examined because easily obtained. It is a transparent greenish liquid, having a ropy character due to admixture with mucus. This last-named characteristic may be demonstrated by pouring the bile from one vessel to another. *Sp. gravity* about 1002. *Reaction* slightly alkaline, or neutral (p. 203). The analysis of bile may be conducted as follows † :—

1. *Mucus.*—Precipitate the mucus by adding to the bile half its bulk of alcohol (83 per cent); filter, wash the precipitate with spirit, afterwards with water, dry in a hot-air chamber, and weigh.

2. *Solid matter.*—Evaporate the fluid obtained by the last operation (which is bile free from mucus) first over a water bath, then under the air pump on a sand bath heated to 100° C. Cool in vacuo, after which allow dry air to pass into the receiver, weigh quickly, and the result will indicate the amount of solid matter. The air may be dried before passing into the receiver by passing it over chloride of calcium.

3. *Fat and cholestrin.*—Pour upon the solid matter obtained

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* Virchow's Archives, xxv. p. 279

† Watt's Dictionary of Chemistry, article—Bile, p. 585.

as above, a few ounces of ether, and allow it to digest for twenty-four hours. Thus an etherial extract of the fat and cholestrin will be obtained, and the amount of these substances can be determined by evaporation and weighing (p. 19). Cholestrin is easily prepared by boiling a little powdered gall stone in alcohol along with a few drops of caustic potash to dissolve fatty matters. From this boiling solution cholestrin separates out in laminæ, often having a small notch at one corner (Plate I. fig. 19).

4. *Bile acids.*—These are taurocholic and glycocholic acids (see p. 12), united with sodium and potassium. They may be obtained by either of two methods.

First method.—After the third operation of removing the cholestrin and fat by ether, an insoluble residue will remain. This must now be treated with cold absolute alcohol, which dissolves the alkaline salts of the bile acids along with a small proportion of pigment. Evaporate the most of the alcohol, add ether to the concentrated alcoholic solution, and set the liquid aside for forty-eight hours in a cool place. A precipitate is thus formed of the bile-acid-salts. Filter, and dry and weigh the precipitate. To estimate the amount of alkali united with the acids, add to the ether precipitate a little sulphuric acid. Thus sulphates of soda and potash will be formed, which may be separated, weighed, and the amount of the alkalies calculated.

Second method.—Add to the bile along with alcohol, basic acetate of lead; filter, wash the precipitate with a solution of carbonate of soda; evaporate to dryness. We thus obtain the sodium salts of the bile acids, to which we add first a little absolute alcohol, and afterwards dilute with water.

The chemical composition of the bile acids has been already given at pp. 12 and 16. It is to be observed that the sulphur of the bile exists in taurin, one of the ingredients of taurocholic acid. The relative quantities of the two acids may therefore be determined by finding the amount of sulphur in the ether precipitate; every six parts of sulphur correspond to 100 parts of taurocholate of sodium.*

5. *The residue*, which is usually very small in amount, contains pigment, alkaline and earthy phosphates, chloride and carbonate of sodium. The amount of inorganic salts may be

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* For the mode of estimating the sulphur see Watt's Dictionary of Chemistry, article—Analysis (organic). Estimation of Sulphur, p. 247.

determined by incineration and subsequent chemical examination.

Bile pigments.—These are five in number (p. 32), but they may be conveniently divided into the brown and the green.

The brown pigments are soluble in chloroform, while the green are not, and thus we have a ready means of separating the two. The *brown* pigments are bilirubin (red) and cholophæin (brown). To distinguish the cholophæin from the bilirubin, according to Brücke,[*] evaporate the chloroform solution, wash the residue with alcohol and ether, until a brick-red powder, soluble in ammonia, is obtained (bilirubin); add to the ammoniacal solution a little hydrochloric acid, and cholophæin will be precipitated as yellowish-brown flakes.

The *green* pigments are represented chiefly by biliverdin, which is insoluble in chloroform, but easily soluble in alcohol, benzol, or disulphide of carbon. The green pigment may be formed from the red pigment by boiling an alkaline solution of the latter; and, according to Städeler, the change may be represented by the following equation:—

$$\underset{\text{Bilirubin.}}{C_{16}H_{18}N_2O_3} + H_2O + O = \underset{\text{Biliverdin.}}{C_{16}H_{20}N_2O_5}$$

The chemical reactions of alkaline solutions of these pigments may be examined as follows:—

Reagent.	Bilirubin.	Biliverdin.
Chloroform.	Soluble.	Insoluble.
Barium chloride.	Precipitate.	No precipitate.
Calcium chloride.	Precipitate.	No precipitate.
Neutral lead acetate.	Red precipitate.	Dark green precipitate.
Silver nitrate.	Red-brown precipitate.	Dark green precipitate.
Nitric acid.	Play of colours ending in a green.	Play of colours ending in a yellow.

Optical properties of bile acids and pigments.—According to Hoppe-Seyler,[†] the bile acids rotate the ray of polarized light to the right. The highest rotatory power is shewn by cholic acid (p. 16). An alcoholic solution of the bile pigments when examined, by the spectroscope, give absorption bands in the vicinity of the letters C and D of the spectrum. Biliverdin absorbs light at both ends of the spectrum, and if not much diluted transmits only green light. A very weak solution absorbs only the extreme red. Numerous modifications of these absorption bands may be obtained by acting on the pigment solution with nitric or hydrochloric acids, or by lead acetate or calcium chloride.*

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[*] Brücke, J. pr. Chem. lxxvii. 72. Jahresb, 1859, p. 637.

[†] Hoppe-Seyler, J. pr. Chem. lxxxix. 257. Bull. Soc. Chim. v. 622.

Tests for bile, bile acids, and bile pigment.—It is often of importance to ascertain the presence of bile in urine or other fluid. For that purpose the following tests may prove serviceable:—

1. *Noel's test for bile.*—Immerse a strip of blotting paper for a few minutes in the fluid, dry, and add a drop of nitric acid containing a little nitrous acid. If bile be present, it will assume a violet colour, changing to red or yellow.†

2. *Pettenkofer's test for bile acids.*—To a little diluted bile, or any liquid containing bile, in a test tube, add a little powdered white sugar, or its equivalent of syrup. Then pour in of strong sulphuric acid (very gradually) rather more than half the bulk of the liquid. By this means the temperature is gradually raised to the proper point, and a deep purplish-crimson colour makes its appearance. This test frequently fails when applied to urine, but if an attempt is made to separate the bile acids by the second method above described, and the test applied to the alcoholic and aqueous solution of the acids, very minute quantities will give the reaction.

3. *The nitric acid test for the bile pigments.*—Place a drop of the suspected fluid on a white porcelain plate, add carefully a drop or two of strong nitric acid, and at the point of contact of the fluid with the acid there will be a play of colours, passing through a red, green, pink, blue, violet, and yellow. The appearance of the green colour, though often evanescent, is indicative of bile. A play of colours may be obtained by the action of nitric acid on the pigment in concentrated urine, but it never shews a green tinge unless bile is present.

4. *The silver oxide test for bile pigments.*—Boil the fluid with an ammoniacal solution of silver oxide. Acidulate the filtrate with a few drops of hydrochloric acid. A purple colour will be produced if biliverdin be present, owing to the formation of an artificial compound called bilipurpin.

Biliary calculi or *gallstones.* — These concretions consist usually of a nucleus of mucus or inspissated bile, which becomes coated with cholestrin. Upon this successive layers of earthy phosphates and carbonates are deposited, often tinged with the bile colouring matter.

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* Jaffe, Zeitschrift f. Chem. [2] v. 666. Maly, ibid. [2] v. 365.

† Noel, J. Pharm. [3] xli. 354.

ANALYSIS OF THE URINE.

This secretion, from its great clinical importance, requires to be carefully examined. Urine may be either healthy or abnormal, that is to say, it may contain normal constituents, such as water, inorganic salts, and organic substances ; or it may contain occasional or abnormal constituents such as blood, albumin, sugar, fat, &c.

1. *Physical properties.*—In its fresh state it is clear, and of a light-yellow colour, has a peculiar odour, a bitter taste, and an acid reaction. With regard to colour, Vogel has classified the numerous varieties of shades of colour we constantly meet with into three groups : 1. Yellow urines ; 2. reddish urines ; 3. brown or dark urines. These again may be subdivided. The varieties of colour depend not on different pigments, but on variations in the quantity of the same pigment. This may be readily shewn by evaporating a light-coloured urine. We find that as the fluid diminishes in quantity, the colour becomes darker. On the other hand, when we dilute any dark-coloured urine, the colour becomes much lighter. The colouring matter of the urine, so far as known, has been already described at p. 34.

The *odour* of urine is affected by food, or medicine, for instance, asparagus, turpentine, saffron, cubebs, &c., may be detected. Turpentine gives urine the odour of violets.

2. *Reaction.*—The urine of carnivorous animals is acid, except during digestion, while that of herbivora is alkaline, except after a prolonged abstinence from food. The cause of the constantly acid reaction of healthy human urine has been disputed. Liebig's view is, that it depends chiefly upon the presence of an acid phosphate, such as NaH_2PO_4. According to the researches of Lehmann, however, there can be no doubt, that in many cases, free hippuric and lactic acids exist in the urine, and consequently assist in giving it its acid reaction.

The urine is alkaline during digestion, owing to the increased elimination of alkaline phosphate, such as Na_3PO_4 derived from the food.

3. *Fermentations of urine.*—Two fermentations occur : 1st, the *acid ;* 2d, the *alkaline.*

When the urine has been left at rest, especially under the influence of a moderate degree of heat, its acid reaction becomes stronger; and distinct crystals of uric acid are often deposited on the sides and bottom of the glass. This increase of its acidity usually goes on for some days, and may even continue in rare instances for two or three weeks. The acidity, however, at last begins suddenly to diminish, and gradually disappears. The urine now becomes lighter in colour; a whitish, iridescent pellicle forms on its surface; and the presence of ammoniacal odour indicates that it has become alkaline. A deposit is thrown down consisting of the ammoniaco-magnesian or triple phosphate, phosphate of lime, and urate of ammonia. This change, the alkaline fermentation, is owing to the decomposition of the urea into carbonate of ammonia. Urea unites with the element of water thus:—

$$\underset{\text{Urea.}}{CN_2H_4O} + \underset{\text{Water.}}{2\,(H_2O)} = \underset{\text{Carbonate of ammonia.}}{(NH_4)_2CO_3}$$

The urine is thus rendered alkaline, and the earthy phosphates are precipitated,—the phosphate of lime as such, and the phosphate of magnesia as the triple phosphate of ammonia and magnesia ($MgNH_4PO_4 + 6\ H_2O$).

4. *Quantity in twenty-four hours.*—The determination of the quantity of urine passed in a given time forms the basis of all quantitative investigations, and must therefore not be overlooked. In all analyses of the urine, the quantity of the fluid, and the time during which it is collected, must be taken into consideration. The time usually adopted is twenty-four hours. The quantity can be determined either by weight or measure; but measure is almost invariably employed for the purpose. The cubic centimetre we take as a standard of unity; one thousand cubic centimetres are equal to a litre, and one litre of distilled water weighs a thousand grammes. When we have learnt the specific gravity of urine, the quantity of which has been ascertained, we may readily arrive at a knowledge of its weight, by simply multiplying the number of ascertained cubic centimetres by the specific gravity of the urine. Thus 1000 C. C. of urine of 1·030 sp. gr. will weigh 1030 grammes. The urine is measured by means of graduated glass jars of different sizes. Care should also be taken in all examinations of urine that the glass vessels are kept quite clean, because a small amount of decomposing

organic matter is sufficient to induce the alkaline fermentation in a few hours.

5. *Amount of solid matter.*—For this purpose we require an accurate chemical balance, several small porcelain crucibles or capsules, a water bath formed of copper plate, a hot air bath or chamber, and a shallow vessel containing a little strong sulphuric acid which can be placed under a bell-jar. The method of estimating the amount of solid matter is as follows :—

(1.) Measure ten cubic centimetres * in a carefully weighed porcelain capsule.

(2.) Evaporate to dryness at a low temperature over a water bath.

(3.) Dry as thoroughly as possible, and afterwards place the capsule in the hot air chamber for several hours.

(4.) Remove the capsule from the chamber, and place it over the sulphuric acid under the bell-jar for two hours.

(5.) At the end of that time remove it, and weigh rapidly. The difference in weight from that of the urine used, gives the amount of solid matter in the urine.

The object of this process is to remove the water as thoroughly as possible. An example will illustrate the calculation :—

Weight of capsule alone -	30·62	grammes.
Weight of capsule with residue	30·84	„
Weight of residue -	0·22	„

Therefore in 10 C. C. of the urine examined there are 0·22 grammes of solid matter. It is important, if a very accurate estimate is required, to weigh several times after the residue has been placed over the sulphuric acid, and not to finish the process until there is almost no difference (say one or two millegrammes) between the two weights. †

6. *Amount of organic and inorganic matter.*—That the residue obtained by evaporating a certain quantity of urine consists partly of organic matter may be easily shewn by the fact that it chars on being strongly heated. If a white heat be applied for some time, the blackened appearance is removed, and a

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[*] The symbol for cubic centimetres is C. C.; for grammes, grms.; for millegrammes, m.grms., &c.

[†] A still more accurate method is described by Neubauer and Vogel in their "Guide to the Qualitative and Quantitative Analysis of the Urine," New Sydenham Society. 1863. P. 153. The method of examining urine described in the text is chiefly that of Neubauer and Vogel.

white ash is left behind. This white ash consists of inorganic salts. The mode of determining the amount of organic and inorganic matter is as follows :—

(1.) Evaporate 10 C. C. of urine in a porcelain capsule.

(2.) When the residue is dry, scrape it out with a small platinum knife, and place it in a weighed platinum capsule (along with from 10 to 13 drops of strong nitric acid or with a known weight of spongy platinum), in which it is to be heated, at first gently, but afterwards strongly. We thus obtain a white ash, free from carbon. The addition of nitric acid converts the urea into nitrate of urea, which when heated is first decomposed into carbonic acid and nitrate of ammonia, and finally escapes as water and nitrous oxide gas. By using nitric acid as an oxidising agent we save time, for the urea, which forms the greatest part of the residue, and produces much carbon at the ordinary red-heat, is thereby removed, and a portion of the remaining carbon more readily oxidises and burns off under the action of the nitrate of ammonia which is formed. We must, however, carefully avoid adding too much nitric acid, and using too great a heat, so as to avoid losing chlorine and phosphorus.

(3.) Weigh the ash with the crucible, and subtract from it the weight of the crucible alone, and the difference gives the actual amount of incombustible salts. Example :—

Crucible with ash - - -	24·656	grammes.
Crucible alone - - - -	24·524	„
Weight of ash in 10 C. C. of urine	·132	„

7. *Amount of water.*—The loss of weight, after evaporating, at a low temperature, 10 C. C. of urine represents the amount of water in 10 C. C.

8. *Specific gravity.*—This may be determined in three ways :—

(1.) *By the specific gravity bottle.*—Ascertain the weight of the bottle alone, then the weight of the bottle filled with distilled water, and thirdly, the weight of the bottle filled with urine. In each operation the bottle must be quite full and carefully wiped dry. Then subtract from each of the last two the weight of the bottle. The proportion then is : weight of water : weight of urine : : specific gravity of water : specific gravity of urine. Example :—

Weight of bottle = 12 Grammes.
Weight of bottle + water = 45 „
Weight of bottle + urine = 46 „

Therefore	33 :	34 : :	1000 :	1030.
	Weight of water.	Weight of urine.	Specific gravity of water.	Specific gravity of urine.

The chief objection to this process is that it is tedious, but with care great accuracy may be attained.

(2.) *By the urinometer.*—We obtain only an approximative knowledge of the true specific gravity of the urine by the aid of the urinometer. This instrument consists of a glass float bearing a graduated stem, and kept upright by a little ball at the bottom containing mercury. It should be graduated so that the zero of the scale be on a level with the surface of the fluid when placed in distilled water, and the degrees should go as high as 1050.

To determine the specific gravity of the urine by means of the urinometer, a proper cylindrical glass is filled with the urine, all froth removed by means of a glass-rod, and the clean urinometer allowed to sink gently into the fluid. The glass should be wide enough to allow the instrument to float freely in the urine, and not to touch its sides. Bring the eye on a level with the surface of the fluid, and read off the scale at the lower level of the curve ‿ formed by capillary attraction ; always read off at that level.

(3.) By glass beads of such a weight that they will float exactly at the surface in fluids of various specific gravities. These beads are numbered from 5 to 50, with many intermediate numbers. If bead No. 20 floats in the fluid so that its upper surface is exactly on a level with the surface of the fluid, the specific gravity of the fluid is 1020.

9. *Christison's method of ascertaining the amount of solid matter from the specific gravity.**—The rule is to multiply the last two figures of the specific gravity, ascertained as above, by 2·33, (a number ascertained from numerous experiments) and the quotient gives the amount of solid matter in 1000 parts of urine. *Example:*—A man passes 46 ounces of urine in 24 hours. Specific gravity, 1025. How much solid matter is excreted?

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* Sir Robert Christison, Bart., Tweedie's Library of Medicine, vol. iv. p. 248, line 6.

—25 × 2·33 = 58·25 oz. of solid matter in 1000 oz. Then 1000 : 58·25 : : 46 : 2·6795 oz. *Answer.*—Amount of solid matter excreted by kidneys in 24 hours, 2·6795 oz.

VOLUMETRIC ANALYSIS.

It is extremely convenient to estimate the amount of certain constituents of the urine by volumetric processes because the analysis is simplified and time is saved. It is therefore essential first, that we understand the theory of the process, for which we are indebted to Gay-Lussac.

Theory of the process.—It consists in submitting the substance to be estimated to certain well-known reactions, using for such reactions, solutions of known strength, and from the quantity of solution employed, calculating the weight of the substance to be estimated according to the laws of equivalence. For example :—

Suppose that it is desirable to know the quantity of pure silver contained in a shilling. The coin is first dissolved in nitric acid, forming a bluish solution, containing silver, copper, and probably other metals. It is known that chlorine combines with silver in the presence of other metals to form chloride of silver, $AgCl$, which is insoluble in nitric acid. The proportions in which the combination takes place are 35·5 of chlorine to every 108 of silver ; consequently, if a standard solution of pure chloride of sodium is prepared by dissolving 58·5 grammes of the salt (*i.e.*, 1 eq. sodium = 23, 1 eq. chlorine = 35·5 = 1 eq. chloride of sodium, 58·5) in so much distilled water as will make up exactly 1000 C. C. by measure ; every C. C. of this solution will contain exactly enough chlorine to combine with 0·108 grammes of pure silver to form chloride of silver, which precipitates to the bottom of the vessel in which the mixture is made. In the process of adding the $NaCl$ solution to the silver, drop by drop, a point is at last reached when the precipitate of $AgCl$ ceases to form. Here the process must stop. On looking carefully at the graduated vessel from which the standard solution has been dropped, the operator sees at once the number of C. C. which have been necessary to produce the complete precipitation of the silver, and as each C. C. equals ·108 grammes of silver, it is easy to calculate the quantity of the latter present in the shilling.

We therefore require in every volumetric process :

1. A solution of the re-agent, the chemical equivalence of which is accurately known. This we term the standard solution (symbol S.S.).

2. A graduated vessel from which portions of it may be accurately delivered—the burette.

3. The decomposition which the solution produces with any given substance is usually of such a character that its termination is unmistakable to the eye, and thereby the quantity of the substance with which it has combined accurately determined. Occasionally, however, we use another solution which produces a characteristic reaction with the standard solution, and which thus informs us when we have added excess of the standard solution. This is termed the *indicator.*

Apparatus required. 1. *The graduated pipette.*—It is made of glass. It serves for measuring the fluid which is to be investigated ; and when filled to the neck, where it is marked by a single stroke or mark, contains 50, 20, 15, 10, 4, or 3 C.C. In using it, its point is introduced into the fluid, and suction made until the fluid has risen above the level of the mark in the neck ; the upper opening is then closed with a moist finger, the pipette dried outside to remove any adherent fluid, and the finger slightly raised to admit a little air, and to allow the fluid to escape until it reaches the level of the mark, the surface of the fluid being kept on the same level as the eye. When the fluid has fallen to this point, the pipette is again firmly closed with the finger, and its contents may now be allowed to run out into any convenient vessel, such as a beaker.

2. *Flasks and Jars.*—These may be graduated from $\frac{1}{10}$th litre to 5 litres. There is usually a mark across the neck indicating the volumetric capacity. It is convenient to have these flasks so arranged that the volumes shall be whole numbers—not $1\frac{2}{3}$ litres, $2\frac{3}{4}$ litres, but 1, 2, 3 litres, and so on.

3. *Mohr's Burette.*—This instrument (Plate XXI. fig. 26, *a*, *c*) consists of a glass tube provided below with a caoutchouc tube *a*, which is closed by a spring clamp *e*. Two or more of these may be fixed into a wooden or iron frame *g*, *h*, *m*, *m*, so as to hang down perpendicularly.

In using it, the pipette is filled up to zero with the volumetrical fluid, the urine to be tested measured out into the beaker glass *l*, and the volumetrical solution then allowed to run out into the glass beaker *l*, by pressing on the clip, and towards the end of the experiment to drop into it, until the proper quantity has been added.* By this arrangement we secure both a rapid flow of the fluid, and also its flow in single drops. In investigations which require some time for their completion, two or more of these burettes are employed ; when completely or half-filled, they are fixed in the stand and there left, their upper opening being closed with a cork to prevent evaporation. Certain standard solutions act injuriously on the caoutchouc and clamp (such as nitrate of mercury in the urea process), and destroy them. In these instances it is advisable to use a burette, having a glass stop cock.

Mode of conducting the process.—In carrying out the volumetrical method of analysis, first carefully prepare the solutions required for the purpose, for upon these solutions the correctness of the analyses depends. Special directions for this object will be given under the head of each particular process. The solutions must always be prepared and used at a given temperature, as their volume varies considerably under the action of heat. Care is also required in reading off the level of the fluid in the different kinds of measures used. Bubbles of air must be removed by a glass rod, so that the surface of the fluid be perfectly level. This point is obtained in the case of the pipette by allowing it to hang freely. We must also allow for the capillarity of the tube. When we examine the curve, especially by transmitted light, several zones are readily distinguished in it. The measurements are most accurate, when (the pipette or the burette having been placed in a perpendicular condition) the eye is brought to a level with the under border of the lowest zone, and the graduation of the tube corresponding with it then read off. This border is most distinctly marked and seen by transmitted light.

When the urine to be tested has been measured, and the pipette or the burette filled with the volumetrical solution, we first of all allow the solution to run slowly out, and at last to pass drop by drop into the urine, until the operation is completed. When the point of completion is shewn in all parts of the fluid, by some distinct reaction, or by the use of an *indicator*, we are sure that the process followed is good ; but if this be not the case, then we must test the mixture again and again towards the conclusion of the experiment, until the right point has been attained.*

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* The volumetrical fluid is usually placed in the burette and the urine in a beaker or porcelain capsule, but occasionally, as in the diabetic sugar process, the reverse is the case.

DETECTION AND ESTIMATION OF THE INDIVIDUAL INORGANIC CONSTITUENTS OF HEALTHY URINE.

Under this head we shall include chlorides, sulphates, phosphates, iron, ammonia, and silicic acid.

1. *Chlorides* (p. 28).—Nitrate of silver always serves as a test for the presence of chlorides in the urine, giving a white curdy precipitate. The phosphoric acid in the urine also throws down a precipitate with nitrate of silver; but this precipitate—phosphate of silver—is soluble in nitric acid, which the chloride of silver is not. Consequently, in testing the urine for chlorine we must, before the nitrate of silver is dropped into it, render the mixture strongly acid by the addition of one or two drops of nitric acid. This will prevent the phosphate of silver being thrown down.

The chlorine exists chiefly in combination with sodium, but a small amount is in the compound of chloride of potassium. The *soda* may be demonstrated in the urine by giving a yellow colour to the inner blow pipe flame, and the *potash* by giving a yellow precipitate of octahedral crystals of the double chloride of potassium and platinum on the addition of the tetrachloride of platinum to an acid and alcoholic solution of the ash.

The amount of chlorides varies considerably. They are much diminished in all acute febrile diseases, the quantity sinking to a minimum, so as sometimes to form scarcely one hundredth of its normal standard. The quantity increases as the disease passes away, and during convalescence is occasionally greater than normal. The presence of a large quantity of chlorine, 6-10 grammes daily, indicates good digestion; a small quantity, under five grammes, weak digestion, provided always that the diet of the patient is not such that only very little chlorine is ingested.

2. *Sulphates* (p. 29).—The sulphates yield, with chloride of

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* In this work, we shall give the volumetric processes for only a few of the constituents of urine, namely, those most important physiologically or pathologically. For details as to the others, reference is made to Neubauer and Vogel, and other works.

barium or nitrate of baryta, a precipitate which is insoluble in mineral acids, and easily detected even when the solution is exceedingly diluted. Consequently, in testing the urine for its sulphates, we first of all render it strongly acid by the addition of a drop of nitric acid or hydrochloric acid, for the same reasons as given in the case of chlorides, and then add to it a solution of chloride of barium or nitrate of baryta. A heavy precipitate falls of sulphate of baryta. If, therefore, we take a certain volume of urine, say 10 C. C., and add to it an equal or sufficient quantity of chloride of barium and hydrochloric acid, we obtain, from the greater or less quantity of precipitate which is thereby thrown down, an approximative estimate of the amount of sulphates present in it.

3. *Phosphates* (p. 28).—These consist of phosphates of the alkalies, and phosphates of the alkaline earths. The latter are insoluble in an alkaline fluid, and consequently are always precipitated when the urine becomes alkaline (p. 262).

Tests for the phosphates.—(1.) Chloride of barium, or nitrate of baryta, give a precipitate of phosphate of baryta, soluble in mineral acids.

(2.) Ammonia, or caustic potash, or caustic soda, give a precipitate of phosphates.

(3.) Perchloride of iron throws down from a solution of phosphates containing free acetic acid, a yellowish-white precipitate of perphosphate of iron.

(4.) Acetate of uranium added to urine containing a few drops of free acetic acid, gives a light yellow or lemon-coloured precipitate, consisting of uranium and ammonium double phosphate.

(5.) Molybdate of ammonia, along with a few drops of nitric acid on boiling yields a brownish, greenish, or canary-yellow precipitate of the phospho-molybdate of ammonia. This is an exceedingly delicate reaction.

VOLUMETRIC PROCESS FOR PHOSPHORIC ACID.

It is often important to determine with accuracy the amount of phosphoric acid excreted in a certain period of time. This is best accomplished by the volumetric process which depends on the fact that a precipitate of uranium and ammonium double phosphate ($2Ur_2O_3NH_4PO_4$) is immediately formed, when a hot solution of a phosphatic salt which is soluble in water or acetic acid, is treated with a solution of acetate or nitrate of uranic oxide in presence of free acetic acid.* The phosphate of uranic oxide thus thrown down, appears as a whitish-yellow, passing even into a greenish, precipitate ; it is completely insoluble in water and acetic acid, but soluble in mineral acids. The exact point of the completion of the reaction cannot be ascertained in the fluid, on account of the slimy character of the precipitate, and of the slowness of its deposition ; consequently, in order to determine whether or not the whole of the phosphoric acid is precipitated, a small excess of uranic oxide must be added,—the presence of this salt being readily shewn by the highly sensitive reaction of the salts of uranic oxide with ferrocyanide of potassium, which gives a reddish-brown precipitate. The ferrocyanide of potassium thus serves as an indicator.

It is necessary, in the first place, to prepare with great care the standard solutions.

(*a.*) *Standard phosphoric acid-solution.*—This solution should be so constituted as to resemble the urine as nearly as possible, as regards the amount of phosphoric acid ; 50 C. C. of it should contain 0·1 gramme of phosphoric acid. It may be readily prepared from chemically pure phosphate of soda, which has not undergone efflorescence. The pure crystals are rubbed down as fine as possible, dried between folds of bibulous paper, 10·085 grammes weighed and dissolved in a litre of water. 50 C. C. of this solution contain exactly 0·1 gramme of phosphoric acid.

(*b.*) *Acetate of soda-solution.*—It has been found 0·5 gramme of acetate of soda is, under all circumstances, sufficient for 50 C. C. of urine. Consequently, 100 grammes of acetate of soda are dissolved in 900 C. C. of water, and the solution brought up to a litre by the addition of 100 C. C. of concentrated acetic acid. In the volumetrical process, 50 C. C. of urine are treated with 5 C. C. of this acid solution of acetate of soda.

(*c.*) *Solution of uranic oxide.*—Pure commercial uranic oxide, is dissolved in pure acetic acid, free from all empyreumatic matters, the solution diluted, and its strength tested with the standard phosphate of soda-solution (*a*). One C. C. of it should precipitate, and indicate the presence of, only 0·005 gramme of phosphoric acid. 50 C. C. of the phosphoric acid-solution (*a*) = 0·1 gramme of phosphoric acid, would consequently require exactly 20 C. C. of the uranic oxide solution; this solution, therefore, must, in the first place, contain 0·4023 gramme of uranic oxide for the precipitation of the phosphoric acid, and, secondly, a slight excess of uranic oxide for the indication of the completion of the reaction.

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* Neubauer and Vogel, pp. 191-193.

50 C. C. of the solution of phosphoric acid require 20 C. C. of the uranic oxide-solution, which again must indicate and precipitate 5 milligrammes of phosphoric acid. If, for example, we employ 18·0 C. C. of the uranic oxide-solution to 50 C. C. of phosphoric acid-solution, we must add to each 180 C. C. of the same 20 C. C. of water. For this purpose we measure off 1 litre of the uranic oxide-solution, and add to it the quantity of water required. In the case supposed, 111·2 C. C. of water must be added to 1000 C. C. of uranic oxide-solution to produce the required degree of strength.

Thus, if we have a second time used 19·8 C. C. of uranic oxide-solution to 50 C. C. of phosphoric acid solution (0·1 gramme of phosphoric acid), we add to each 198 C. C. of the same 2 C. C. of water, and make a new and final test with the phosphate of soda-solution.

The uranic oxide-solution, each cubic centimetre of which precipitates 5 milligrammes of phosphoric acid, and which also contains a small excess of uranic oxide for the final re-action, must contain 20·3 grammes of pure uranic oxide in a litre.

Process for the whole of the phosphoric acid with acetate of uranium, ferrocyanide of potassium being used as an indicator.

1 C. C. of S. S. = 0·005 grammes of phosphoric acid.

(1.) Place 50 C. C. of filtered urine in a beaker.

(2.) Add to it 5 C. C. of a solution of sodium acetate.

(3.) Drop in standard solution of uranium acetate, until a drop gives a faint brown colour when mixed with a drop of potassium ferrocyanide, on a porcelain plate.

(4.) Boil and test again. If necessary, add a few drops more of the S. S. until the brown colour again appears immediately on testing.

Example.—Patient passes in 24 hours 1000 C.C. of urine ; 25 C. C. of S. S. are used in volumetric process for phosophoric acid. How much phosphoric acid is excreted :—·005 × 25 = ·125 grammes in 50 oz. Then 50 : ·125 : : 1000 : 2·5 grammes, the quantity in 1000 C. C. of urine.

Process for estimating the amount of phosphoric acid united with the alkaline earths.

(1.) Take 100 C. C. of filtered urine, and make it alkaline with ammonia. The earthy phosphates are thus precipitated.

(2.) Let the urine stand for 12 hours.

(3.) Collect the earthy phosphates on a filter, and wash with ammonia water.

(4.) Wash precipitate into a beaker, heat and dissolve in a few drops of acetic acid.

(5.) Add 5 C. C. of acetate of sodium solution, and add water to make up volume to 50 C. C.

(6.) Proceed with acetate of uranium solution as before, and make the necessary calculation.

Taking the previous example, we find that :—

The whole of the phosphoric acid, as determined by acetate of uranium process, is		2·5 grammes.
Phosphoric acid with the earths required 5 C. C. of S. S. Therefore, ·005 × 5 = ·025 grammes in 100 C. C. of urine. Patient passed 1000 C. C. Therefore, in 1000 C. C. we find of phosphoric acid united to the alkaline earths, -	0·25	
Phosphoric acid with alkalies, -	2·25	
		2·5 grammes.

4. *Iron.*—This is rarely found in urine, and only in very minute quantities. It probably exists in the colouring matter. For testing and ascertaining the presence of iron in the urine, the ash obtained from the urine is always employed. Dissolve in a few drops of hydrochloric acid. Boil with a drop of nitric acid, and add a drop of sulphocyanide of potassium, thereupon the fluid will assume a reddish colour, and if a considerable quantity of iron be present, a deep dark-red colour. When mere traces are present, the change of colour is best observed by placing the tube over a white ground.

5. *Ammonia.*—According to Neubauer and Vogel, a small amount of free ammonia is present even in acid urine, but its quantity is so small as to render its detection extremely difficult. It is of no importance.

6. *Silicic acid.*—This acid has been detected in very small amount by incinerating the ash of urine with sodium and

potassium carbonate, dissolving the ash in water, and acidulating with hydrochloric acid. On again evaporating to dryness, the silicic acid remains behind in a pure state.

DETECTION AND ESTIMATION OF THE INDIVIDUAL ORGANIC CONSTITUENTS OF HEALTHY URINE.

These are urea, uric acid, hippuric acid, creatin and creatinin, xanthin, and benzoic, phenylic, damaluric, damolic, and succinic acids.

1. *Urea* (p. 14 and p. 25).—This substance may be prepared from the urine by first precipitating all the phosphates by means of baryta, filtering, evaporating the filtrate, and treating the residue with alcohol. This alcoholic solution is evaporated to dryness, and the product again treated with pure alcohol. We thus obtain an alcoholic solution of urea, which crystallises out on evaporation. The most important salt of urea is the nitrate, which may be obtained by mixing a concentrated solution of urine or urea with concentrated and pure nitric acid. It then appears as white plates.

Tests for Urea.—(*a.*) When the quantity of urea is small, the formation of nitrate of urea may be observed under the microscope, and in the following way:—One end of a little bit of thread is laid in the drop which is to be tested for urea; the drop itself and one-half of the thread is then covered with the glass, and the other end of the thread moistened with a drop of pure nitric acid. In this way, the two fluids being gradually mixed together, we may see the formation of crystals of rhombic plates or short prisms, as well as numerous complicated forms.

(*b.*) When a solution of nitrate of mercury is added to urine, we obtain a white floculent precipitate, which varies in composition according to circumstances. It may, according to the quantity of urea present, consist of mercuric oxide and nitrate of urea, or urea combined with mercuric nitrate and mercuric oxide. Upon this reaction, however, the volumetric process is based.

VOLUMETRIC PROCESS FOR UREA.

When a dilute solution of urea is added to an equally dilute solution of nitrate of mercury, and the free acid neutralised by carbonate of soda, a white precipitate is obtained. After all the urea has been precipitated, we reach a point where the yellow-coloured hydrated oxide of mercury is thrown down by the carbonate of soda, carbonic acid escaping with effervescence. It has been found by analysis that the urea is thrown down in combination with oxide of mercury, and that the precipitate contains four equivalents of oxide of mercury to one equivalent of urea. The exact point, or rather the exact point has just been over-stepped, when all the urea is precipitated, and is known by the formation of a yellow pellicle on the surface of a drop of carbonate of soda mixed with a drop of the fluid being examined for urea.

Preparations of standard solutions. (*a.*) *Standard solution of urea.*—Four grammes of pure urea, dried at 100° C., are dissolved in water, and diluted until the volume of the fluid equals 200° C. C. Thus 10 C. C. = ·2 grammes of urea.

(*b.*) *Standard solution of nitrate of mercury.*—Pure oxide of mercury best serves for the preparation of the mercury solution. Commercial oxide of mercury may be obtained sufficiently pure for the purpose. An oxide of mercury which leaves no visible residue when heated on platinum foil is fitted for the purpose. Of this oxide 77·2 grammes, dried at 100° C. are taken by weight, dissolved under a gentle heat with the smallest possible quantity of nitric acid in a porcelain basin, evaporated to a syrup, and then diluted with water up to a litre. Should any basic salt separate, a few drops of nitric acid are dropped into it until the precipitate re-dissolves.

The next step is to graduate the prepared solution of mercury by means of the standard solution of urea. For this purpose 10 C. C. of the urea-solution are measured off and placed in a beaker, the dilute mercury solution is then added to it, until a few drops of the mixture, added to a drop of carbonate of soda on a watch-glass, give a yellow colour. If, for example, to obtain this reaction, we use 19·25 C. C. of the mercury solution, we add to each 192·5 C. C. of the mercury solution, 7·5 C. C. of water, and thus get 200 C. C. of a solution, 20 C. C. of which will precipitate the urea from exactly 10 C. C. of urea solution (that is ·2 grms.). Thus 10 C. C. of mercuric nitrate solution will correspond to ·1 grms. of urea.

Process for estimating Urea with Nitrate of Mercury, Carbonate of Soda being used as an Indicator.

(1.) If albumin be present in the urine, separate it by boiling and filtration.

(2.) Mix the urine with half its volume of a solution called "baryta mixture" (composed of two volumes of solution of Barium hydrate with one volume of Barium nitrate, both saturated in the cold).

(3.) Filter to get rid of Barium sulphate and phosphate.

(4.) Take 15 C. C. of filtrate (=10 C. C. of urine) and place in a beaker.

(5.) Drop in S. S. till precipitate ceases, testing the mixture from time to time with a solution of sodium carbonate, until a faint yellow reaction is obtained.

We thus obtain a knowledge of the quantity of urea in 10 C. C. of urine.

Example.—Patient passes in 24 hours 1000 C. C. of urine, 14 C. C. of solution of mercuric nitrate are employed. How much urea is excreted? 1 C. C. of mercuric nitrate solution =·01 grms. of urea ∴ 14 C. C. = ·14 grms. in 10 C. C. of urine. Then 10 : ·14 : : 1000 : 14 grms. of urea, the quantity in 1000 C. C. of urine.

*Corrections for urines containing more or less than two per cent. of urea.**—The reaction between mercuric nitrate and carbonate of soda is exact only for fluids containing two per cent. of urea, and we require 30 C. C. of S. S. for complete precipitation of the urea in every 15 C. C. of urine, as well as for the reaction with sodium carbonate. When the urine contains more than two per cent. of urea the reaction takes place too soon, when it contains less the reaction is delayed.

(*a.*) *With more than two per cent. or excess of urea.*—When double the volume of mercurial solution has been used, and no reaction set in, 1 C. C. of distilled water is added to the mixture for every additional 2 C. C. of the mercurial solution used, and thus the proportion of urea is maintained at two per cent. Thus, if 30 C. C. of solution of mercuric nitrate are added to 15 C. C. of urine, and the reaction is not seen, 1 C. C. of distilled water is added, and the process is continued. If the reaction set in when 10 C. C. more, or 40 C. C. in all, of the mercurial solution have been used, the 5 C. C. of distilled water added (*i.e.* 1 C. C. of water for every 2 C. C. of the excess over 30 C. C.) will, with the original 15 C. C. of urine, make 20 C. C., and the mercurial solution will have been employed on a urine containing two per cent. of urea.

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* Corrections must also be made, if great accuracy be desired, for the chloride of sodium, and carbonate of ammonia, but as these are not very important, reference is made to Neubauer and Vogel, p. 185.

(*b.*) *With less than two per cent of urea.*—If the urine contain less than two per cent. of urea, subtract ·1 C. C. from every 5 C. C. of mercurial solution less than the normal 30 C. C. Thus, if with 15 C. C. of urine, the reaction with sodium carbonate is got on using 20 C. C. of solution of mercuric nitrate, ·2 C. C.—that is ·1 × 2, are deducted, and 19·8 C. C. taken as correct.

2. *Uric acid* (pp. 13, 357).—The presence of this acid may be readily demonstrated in urine by placing a few ounces in a conical glass, adding a few drops of hydrochloric acid, and allowing it to stand for forty-eight hours. Uric acid then crystallises out, and appears on the surface of the fluid and adhering to the bottom and sides of the glass. When examined microscopically, the crystals will be found as represented in Plate I. figs. 1 and 2.

The murexide test for uric acid.—Place a few drops of urine on a large flat porcelain lid. Add a drop of nitric acid. Evaporate nearly to dryness, and then bring a glass rod dipped in a solution of ammonia over the residue. A splendid purple-red or violet colour of murexide is produced. In this test the nitric acid frees uric acid from its union with bases, and converts it into two substances termed alloxan and alloxantin (p. 13). A compound called murexide or purpurate of ammonia is then formed by the union of the ammonia with these two uric acid derivatives.

*Schiff's test for uric acid.**—Dissolve the suspected powder in sodium carbonate, and place a drop of the solution on a bit of blotting paper moistened with nitrate of silver solution ; if uric acid be present, a brown spot appears, carbonate of silver being reduced to oxide by uric acid at ordinary temperatures.

Garrod's test for uric acid present in small quantity.†—This test is more especially applicable to the detection of uric acid in the blood. Take about two drachms of the serum and place it in a flat glass dish or watch-glass. To this add twelve drops of ordinary strong acetic acid, which will cause the evolution of a few bubbles of gas. When the fluids are mixed, introduce two or three threads of unwashed cotton. Allow the glass to stand on the mantel-piece, or on a shelf in a warm room, for from thirty-six to sixty hours, until its contents set, from evaporation. If the cotton fibres be then removed and examined microscopically with a half-inch object-glass, they will be found covered with crystals of uric acid, if this agent be present in the serum. The crystals form on the thread somewhat like masses of sugar-candy on string.

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* Schiff. Ann. Ch. Pharm. cix. 65.

† Garrod On Gout. London. 1863.

3. *Hippuric acid* (p. 15).—This acid exists in very minute quantity in human urine, more especially after a person has taken benzoic acid, toluene, cinnamic, or mandelic acids, but it may be readily prepared by treating the urine of a cow or horse with excess of lime water, and thus precipitating it as hippurate of lime. Evaporate to 1-10th of the original volume of the urine, and add hydrochloric acid. Hippuric acid crystallises out impure, but the crystals may be obtained colourless and semi-transparent by dissolving them in water in the presence of animal charcoal, and allowing them again to crystallise out (Plate I. fig. 5).

4. *Creatin and creatinin* (p. 18).—Urine contains only a small quantity of creatin and creatinin, so that a large amount of the fluid is required for their demonstration. The mode of separating these from urine is as follows:—Three hundred C. C. of fresh urine are neutralised with milk of lime, and the phosphoric acid then thrown down by a solution of chloride of calcium. Filter and quickly evaporate to dryness in a water-bath. The residue thus obtained is extracted with absolute alcohol, allowed to stand for some hours, and again filtered; the clear fluid is then treated with a few drops of a concentrated solution of chloride of zinc free from acid. The mixture becomes turbid, and the separation of the creatinin-chloride of zinc is completely effected in forty-eight hours. The compound is washed on a filter with spirits of wine, dried, and microscopically examined (Plate I. figs. 11 and 12).

To obtain the creatinin in a pure state, dissolve the zinc compound in a small quantity of boiling water, and separate the oxide of zinc and hydrochloric acid by boiling the fluid with freshly-precipitated and well-washed hydrated oxide of lead. The filtered liquid is rendered colourless by boiling with animal charcoal, and evaporated to dryness. The residue, which consists of a mixture of creatinin and creatin, is then treated with cold strong spirits of wine, whereby the creatinin is dissolved and the creatin left.

Should the urine operated upon contain albumin, the albumin must be previously separated from it by coagulation.

5. *Xanthin* (p. 16).*—The mode of preparing this substance from urine is as follows:—Fresh, healthy urine, in quantity not less than from 100 to 200 pounds, is evaporated in a water-bath to from one-sixth to one-eighth of its original volume, and its phosphoric acid removed by precipitation with baryta-water. The filtrate is again evaporated until the salts are crystallised out of it ; the mother-liquor thus obtained is then well diluted with water, a solution of acetate of copper added, and boiled for some time. A dirty-brownish precipitate is thus obtained, which is first decanted and then washed on the filter with cold water until all chlorine-reaction has disappeared. By treating this precipitate with hot nitric acid, we obtain a brownish solution, from which the impure xanthin-silver compound is precipitated by nitrate of silver. The crystalline compound, after being washed, is dissolved in boiling dilute nitric acid ; any remaining flocculi of chloride of silver are removed by filtration, and the filtrate set aside and allowed to crystallise slowly. The collected crystalline silver-compound is freed from nitric acid by digestion with an ammoniacal solution of silver ; the washed precipitate diffused through water, boiled, and the compound decomposed by sulphuretted hydrogen. The boiling filtered solution deposits, when concentrated, coloured flocculi of xanthin, and the remainder is obtained by further evaporation. The preparation thus obtained is, however, always much discoloured ; but by solution in strong hydrochloric acid and treatment with animal charcoal, the purification is readily effected. The filtrate, thus freed from colour, yields, when evaporated, hydrochlorate of xanthin, from which pure xanthin may be obtained by repeated treatment with ammonia, and by subsequent removal of the chloride of ammonium by washing with cold water.

6. *Benzoic*, *phenylic*, *taurylic*, *damaluric*, *damolic*, *succinic*, *oxalic*, *formic*, *lactic*, *and acetic acids.*—Human urine contains only a very small and variable quantity of these acids. Acetic and butyric acids are usually to be found in decomposing urine. It is not within the scope of this work to describe the various processes by which these substances can be obtained from urine, and reference is made to larger works on Physiological Chemistry.

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* Neubauer and Vogel, p. 24.

DETECTION AND ESTIMATION OF THE ABNORMAL CONSTITUENTS OF URINE.

We shall consider the following: albumin, sugar, bile pigment, bile acids, fat, kiestein, lactic, acetic, and butyric acids, sulphuretted hydrogen, allantoin, leucin, and tyrosin.

1. *Albumin.*—This substance is occasionally present for a short time in healthy urine, but as a rule its presence is indicative of disease of the kidneys. It is therefore of the greatest importance to be able to detect it even in minute quantity. Albumin is always present in urine containing blood.

Tests for albumin. (*a.*) *Heat.*—In the first place, test the reaction of the urine with litmus paper. If it be alkaline, or neutral, add to it a few drops of acetic or nitric acids; if very acid, carefully neutralise with a little dilute ammonia. Boil a small quantity in a test tube. If albumin be present in small amount, the fluid will become turbid when the heat exceeds 68° C.; if it be abundant, there will be a distinct coagulation. It is important to remember that if the urine be either alkaline or neutral, coagulation may not take place—the albumin, if present in small quantity, uniting with the alkali. On the other hand, if a small amount of albumin be present in a large quantity of water, and there be excess of acid, no coagulation may follow, because a combination of albumin with the acid may be formed, which is soluble in water. Another fallacy to be remembered is, that upon boiling certain varieties of urine, a precipitate of earthy phosphates takes place, which, however, can be readily distinguished by the addition of a little dilute nitric acid, which dissolves the phosphates, but not the albumin.

(*b.*) *Nitric acid test.*—On adding nitric acid to urine a white turbidity occurs if albumin be present in small, and distinct coagulation if present in large, amount. Sometimes, however, no coagulation is obtained because nitrate of albumin is formed, which is soluble in a large quantity of water; in other specimens of urine, a precipitate of nitrate of urea may be formed, which, however, is readily detected by means of the microscope; while in the urine of patients in the habit of taking copaiva, cubebs, and other oleo—and resinous—medicines, a white turbidity appears, which, however, does not sink to the bottom of the test tube as albumin does, but will remain for many hours suspended in the fluid.

(*c.*) *Ferrocyanide of potassium test.*—When to a well-filtered urine, acidulated with acetic acid, a weak solution of ferrocyanide of potassium (5 grains to the ℥i) is added, there is a white precipitate. If there be a large quantity of mucus in the urine, this test is not serviceable.

In testing for albumin, therefore, it is better to employ both heat and nitric acid than either alone, and if the above sources of fallacy are borne in mind, there is usually no difficulty in detecting even minute traces of albumin.

Estimation of the quantity of albumin by weight.—Place 20 C. C. of urine, diluted with 80 C. C. of water, in a beaker, and allow the albumin to coagulate in a water bath. Collect the coagulum on a filter, wash and dry it at 100° C., weighing occasionally until there is no appreciable difference between two weighings. This is albumin with inorganic matter. Incinerate, and collect and weigh the ash. Deduct this from the weight of albumin + inorganic matter, and the difference will be a very near approximation to the amount of albumin. *Example.*—Patient passes 1000 C. C. of urine in 24 hours. 20 C. C. yielded ·454 grammes of albumin + ash. After incineration, the ash was found to weigh ·0015 grammes ∴ $\cdot454 - \cdot0015 = \cdot4525$ grammes in 20 C. C. In 1000 C. C. therefore, the amount of albumin would be $\cdot4525 \times 50 = 22\cdot625$ grammes.

There is also a volumetric process for albumin depending on the fact that albumin is precipitated by ferrocyanide of potassium, but it is open to so many objections that the process by weight is always preferred.

2. *Sugar.*—The variety of sugar found in urine is grape sugar $C_6H_{12}O_6$ frequently termed diabetic sugar. Brücke has demonstrated that sugar in small quantity may frequently be found in healthy urine ; but its constant presence in large amount in urine constitutes the disease known as diabetes (διὰ, through, and βαίνω, I pass). The urine in this disease is usually light coloured, froths readily on being poured from one vessel into another, and has a high specific gravity.

Preparation of diabetic sugar from urine.—Evaporate urine to consistence of syrup, and allow the sugar to crystallise out. It is still impure, being mixed with urea and extractive matters. Separate these by means of absolute alcohol, and then add to the residue spirits of wine which will dissolve the sugar. It is again allowed to separate out from this solution, and the crystalline masses purified from alcohol by repeated re-crystallisations from water. When thus obtained, it is white, and crystallises in little lumps. These are composed of crystals belonging to the rhombic system.

Tests for sugar in urine. (*a.*) *Moore's test with caustic potash.*—To the suspected urine add an equal bulk of solution of caustic potash, and boil. If sugar be present, a deep orange-brown (like dark sherry) will be obtained. If sugar be present in large quantity, the colour is dark purple, and frequently almost black. This colour is produced by the action of KHO on $C_6H_{12}O_6$ producing melassic and glucic acids. The caustic potash used should be freshly prepared, because if allowed to stand for a length of time in a glass bottle, it becomes contaminated with lead, which, acting on the sulphur of urine, produces black sulphide of lead, and gives rise to a deceptive colour.

(*b.*) *Trommer's test with sulphate of copper and caustic potash.* To the urine add a few drops of solution of sulphate of copper. To this add a little caustic potash. This throws down a greenish blue precipitate of hydrated cupric oxide ($CuOH_2O$), which is dissolved in excess of the caustic potash, forming a blue liquid. Heat this by applying the flame of the lamp to the upper stratum of the fluid, and if sugar be present, a yellow, or orange, or red precipitate of cuprous oxide (Cu_2O) will be formed, which will form a marked contrast to the blue liquid in the bottom of the test tube. This test depends on the fact that diabetic sugar has the property of reducing cupric oxide to cuprous oxide. It does not do so directly, but indirectly, by its decomposition by the action of caustic potash, into melassic acid, which has a strong tendency to unite with oxygen. Unfortunately, however, other substances, such as excess of urates, or the protein compounds occasionally present in urine, have the same property, especially with the assistance of prolonged boiling, and it is consequently often difficult to detect minute traces by means of this test. If the cupric oxide be reduced to cuprous oxide *in the cold*, we may be sure diabetic sugar is present.

(*c.*) *Fehling's test with potassio-cupric tartrate* ($K_2Cu2C_4H_4O_6$).—The composition and mode of preparing this solution will be subsequently described when treating of the volumetrical estimation of sugar (p. 482). A few drops of it are added to the urine, and the upper stratum boiled. If sugar be present, it will reduce the cupric oxide in the alkaline tartrate to cuprous oxide, and give the same reaction as in Trommer's test. If freshly prepared, Fehling's solution will often detect minute traces of sugar, but it is liable to decomposition if kept for even a week, and occasionally it gives uncertain results, even when the presence of sugar has been ascertained by the other tests.

(*d.*) *Böttcher's test with nitrate of bismuth.*—Add to the urine an equal volume of a solution of carbonate of soda (3 parts of water to 1 part of crystallised Na_2CO_3), and afterwards a little trisnitrate of bismuth, and boil. If the white powder become dark, sugar is present, owing to the fact that sugar has the power of reducing the oxide of bismuth. If albumin be present in the urine, it must be first got rid of by boiling and filtration, because the sulphur of the albumin may readily form with the bismuth black sulphide of bismuth.

(*e.*) *Dichloride of tin test.*—Moisten a few strips of merino in a solution of stannous-chloride, and dry in a water bath. On moistening one of these strips with diabetic urine, and holding it near the fire, a brownish-black colour will make its appearance.

(*f.*) *Fermentation test.*—Ordinary yeast is mixed with water, and a long test-tube filled with the suspected urine, to which some of the yeast has been added. The tube is then inverted over a saucer containing the urine under examination, so that no air may enter, and the whole is set aside in a warm place. If sugar be present, it will be decomposed under the action of the yeast into carbonic acid and alcohol, and the gas will speedily collect in the upper part of the tube. Another mode of demonstrating the change is to conduct off the carbonic acid by a fine tube into lime-water, which of course at once becomes turbid from the formation of insoluble carbonate of lime.

Estimation of the amount of sugar.—This may be done in two ways: (1.) by a volumetrical process; and (2.) by means of an instrument termed a saccharimeter.

1. *Volumetric process for Diabetic Sugar.*

This process is founded on the property already mentioned which diabetic sugar possesses of reducing cupric oxide to cuprous oxide. If we use, therefore, a solution of potassio-cupric tartrate which contains, in a given volume, a quantity of cupric oxide that is reduced by a certain quantity of sugar, we can estimate the amount of sugar in solutions of unknown strength by finding the volume required for the decomposition of a fixed quantity of copper solution.

Preparation of the copper solution (*Fehling's solution*).—34·65 grammes of pure crystallised sulphate of copper are dissolved in about 160 grammes of water; and a solution of 173 grammes of pure crystallised double tartrate of potash and soda is treated with from 600 to 700 grammes of caustic potash of 1·12 sp. gr. Into the latter solution the sulphate of copper solution is gradually poured. The clear mixture is then diluted up to a litre. It has been found that 10 C. C. of this copper solution are reduced by exactly 0·05 gramme of diabetic sugar. In order to preserve the copper solution for a length of time, it is necessary to keep it in a dark place, in small stoppered glass bottles (containing 1 or 2 ounces).

Process.—(1.) Filter the urine.

(2.) Dilute the urine with 20 times its bulk of distilled water, and place it in a burette.

(3.) Dilute 10 C. C. of standard solution (=·05 grammes of sugar) with 20 to 30 parts of distilled water, and place it in a porcelain capsule, under the burette.

(4.) Boil, gradually adding the diluted urine from the burette, until the cuprous oxide has been precipitated as a reddish powder, and the supernatant liquid has acquired a straw-yellow colour, not a trace of blue remaining.

(5.) Filter the *boiling* fluid, and divide into three portions:

- *a.* 1st portion.—Add a few drops of hydrochloric acid, and afterwards a little of a solution of sulphuretted hydrogen. The absence of a black colour indicates that all the cupric oxide has been reduced.
- *b.* 2nd portion.—Add a few drops of acetic acid, and then test with ferrocyanide of potassium. The absence of a reddish brown colour or precipitate indicates that all the cupric oxide has been reduced.
- *c.* 3rd portion.—To guard against the error of adding too much urine, add to this portion a few drops of the copper solution, and boil. If a trace of sugar be present, a reddish colour will appear in a short time.

Example—Patient passes 15,000 C. C. of urine, 36 C. C. of dilute urine were required to reduce all the cupric into cuprous oxide in 10 C. C. of standard solution. How much sugar was passed? 10 C. C. of S. S. require exactly ·05 grammes of sugar to effect the reduction. 36 C. C. of dilute urine=1·8 C. C. of real urine (20 : 1 : : 36 : 1·8) .·. 1·8 C. C. of real urine contain ·05 gramme of sugar. Then 1·8 : ·05 : : 15,000 : 416·$\dot{6}$ grammes of sugar in 15,000 C. C. of urine.

2. *Estimation of Sugar by the Saccharimeter.*

It is well known that diabetic sugar, in common with cane sugar, milk sugar, camphor, &c., have the property of rotating the plane of the vibrations of a ray of polarised light to the right (p. 142). It has been found also that the angle of deviation is in proportion to the length of the column through which the ray passes, or to the quantity of the substances contained in a column of given length. The saccharimeter of Soleil consists essentially of four parts : 1. A glass tube, for containing the fluid to be examined, fitted into a brass case, and closed at both ends with plate-glass discs ground to fit water-tight, and kept tightly in their place by means of screw-caps. This is placed on a support between a polarising and analysing apparatus. 2. A polarising apparatus consisting of an achromatic calc-spar prism, having a small screen behind it (that is nearer the tube containing the solution) which intercepts one of the images ; and a double plate of quartz, one half being dextro,—and the other lævro-rotatory. 3. An analysing apparatus, consisting of a quartz plate cut perpendicularly to its axis, and a doubly refracting prism, fitted into a small telescope ; and, 4. An apparatus, termed a *compensator*, which is placed between the quartz plate and doubly refracting prism just mentioned. This consists of two elongated quartz prisms cut perpendicular to the axis, each one being narrower at one end than at the other, and set on two racks moved horizontally by a toothed pinion, so as to vary the thickness which the modified light has to traverse. One rack carries a scale (tenths of a milimetre), the other a vernier (tenth of the tenth of a milimetre=1-100th of a milimetre) so as to measure the displacements of the prisms.

Mode of using the saccharimeter.—The instrument is placed before a bright light, the polarising apparatus being next the light. The tube is filled with distilled water, care being taken to exclude all bubbles of air, and is placed between the polarising and analysing apparatus. The eye is now directed to the telescope. If the instrument be correct, a disc of coloured light is seen, divided into two hemispheres by a very faint dark line, when the zeros of the vernier and scale coincide. The tube is now emptied of distilled water, carefully dried, and filled with urine which has been prepared by adding to it a solution of acetate of lead, and filtering. When the polarised light is allowed to pass through this stratum of urine containing diabetic sugar, the two hemispheres will now be found to have different colours, say one red and the other blue, and the object is now to bring back the two hemispheres to the same tint by moving the compensating prisms, which is done by turning a screw attached to the pinion already mentioned. By thus moving the compensator, we produce an inversion of the rotation of the ray of polarised light opposite to that produced by the liquid, and the displacement of the vernier gives the angle of deviation—the thickness of quartz corresponding to one division of the scale being known. The number of degrees on the scale is now read off, and each degree corresponds to a certain amount of sugar in a known quantity of urine. The instrument in use in the physiological laboratory of Edinburgh University, is so adjusted that each degree of the scale corresponds to ·111 ounces of diabetic sugar in 50 ounces of urine. Thus, suppose a patient passes 200 ounces of urine in 24 hours, How much sugar is excreted? The urine is examined as above, and it is found that the zero of the vernier is opposite 28 of the scale when the tints of the hemispheres are exactly the same. Then $28 \times {\cdot}111 = 3{\cdot}108$ oz. in 50 oz. $\therefore 3{\cdot}108 \times 4 = 12{\cdot}432$ oz. in 200 oz of sugar.*

3. *Bile.*—Urine containing bile has a peculiar greenish-black colour. The tests for bile acids and bile pigment have already been described at p. 458, while treating of bile.

4. *Fat.*—Occasionally fat is found in the urine in the form of oil globules, but it is usually associated with fatty casts, indicating an advanced condition of Bright's disease.

5. *Chylous urine.*—This urine is white, from the abundance of fatty molecules it contains. Sometimes albumin is present when it coagulates on cooling. It is probable in these cases there may be some abnormal communication between the lacteal system and the ureters or kidney.

6. *Kiestein.*—The urine of pregnant women often shews a fat-

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* For a complete description and figure of the saccharimeter, see Watt's Dictionary of Chemistry—article, "Light." Vol. iii. p. 674. Also Desplats et Gariel's Nouveau Eleménts de Physique Médicale. Paris, 1870, p. 396.

like scum on the surface, which consists of crystals of triple phosphate, fat globules, and a granular matter of an albuminous nature called kiestein. When kept, it smells like old cheese.

7. *Lactic acid.*—This acid is rarely found in urine, and its presence cannot be determined by any special test, but by the following mode of procedure: Evaporate fresh urine nearly to dryness, and treat the residue with a solution of oxalic acid in alcohol. Oxalates are thrown down, while the lactic acid remains in solution. This fluid is then digested with litharge, evaporated to dryness, and an alcoholic solution of lactate of lead obtained. This, in turn, is decomposed by sulphuretted hydrogen, the sulphide of lead filtered off, and the fluid evaporated to a syrup. The syrup is now shaken up with ether, the etherial solution of lactic acid evaporated, and the lactic acid dissolved in water. The aqueous solution is now boiled with zinc oxide and the crystals of lactate of zinc are allowed to separate.

8. *Acetic and butyric acids.*—These are found only in decomposing urine, and it is not important to detect or isolate them.

9. *Sulphuretted hydrogen.*—This gas has rarely been found in urine. It may be readily detected by blackening a piece of paper dipped in a solution of acetate of lead and held over it.

10. *Allantoin* (Pl. I. fig. 8).—Schottin has found this substance in the urine of a man who had taken a large quantity of tannic acid. It has also been found in the urine of young children, but it is probable its presence is only temporary. Its detection is of no practical importance.

11. *Leucin* (Pl. I. fig. 10).—This product has been found in the urine of individuals suffering from hepatic disorders. There is no chemical test for its presence, and it can only be identified in deposits by microscopical examination. It usually is found in the form of roundish, yellowish coloured balls, which consist in reality of masses of small needle-like crystals.

12. *Tyrosin* (Pl. I. fig. 9).—It is formed under the same conditions as favour the production of leucin, and like it, can be identified only by means of the microscope. It consists of stellate groups of long silky needles, not in balls or coloured, as is the case with leucin.

Examination of the Sediments of Urine.

These may be conveniently divided into 1. those occurring in acid or alkaline urine, namely, uric acid, urates, phosphates, oxalates, and cystin; 2. those found in alkaline urine only, namely, the ammoniaco-magnesian, or triple phosphate, phosphate of lime, and urate of ammonia; and 3. organised deposits, namely, mucus, blood, pus, tube casts, spermatozoids, torulæ, sarcinæ, bacteria, vibriones, &c.

1. *Deposits found occasionally in acid or alkaline urine, usually in the former.*

(1.) *Uric acid* (Pl. I. figs. 1, 2).—This appears as a yellow, reddish, or brown coloured sediment, consisting of little masses of crystals. It assumes various crystalline forms: (*a.*) lozenge-shaped rhombs; (*b.*) rectangular tables or prisms; (*c.*) dumb-bell crystals; and, (*d.*) spindle or barrel-shaped forms.

(2.) *Urates.*—These appear when the urine is cold, if the salts are present in excess, because urates are much more soluble in hot water than in cold. Consequently, every deposit which disappears on heating consists of urates. They usually form a heavy precipitate at the bottom of the glass, presenting an ill-defined upper border. The deposit may be white, or deeply tinted by the colouring matter of the urine. Such deposits have been termed "lateritious deposit," "brick-dust deposit," "critical deposit," and "purpurates." (*a.*) *Urate of Soda* is amorphous in urine, but when prepared artificially, by acting with uric acid on sodium phosphate, it forms acicular crystals (Plate I. fig. 3). (*b.*) *Urate of ammonia* appears as an amorphous granular sediment, or in the form of brown round balls covered with spines (Plate I. fig. 4 and fig. 18, *b*). (*c.*) *Urate of lime* is very rare, and appears as a white amorphous powder.

(3.) *Phosphates.*—In acid urine, phosphates may be present in excess, when they appear as a cloudy precipitate, at once soluble in a drop of nitric or hydrochloric acids.

(4.) *Oxalate of lime* (Plate I. fig. 17).—This salt is easily detected by its characteristic crystals, which are octahedra (*a.*) or dumb bells (*b.*). It is not found as a distinct sediment, but exists as isolated crystals entangled in the mucous cloud with which it is usually associated.

(5.) *Cystin* (Plate I. fig. 6).—This is occasionally found as a sediment mixed with amorphous urates. Under the microscope its transparent, colourless, six-sided plates can scarcely be mistaken. If it exist in large quantity along with urates or phosphates, or both, it may be distinguished from them by heating and adding acetic acid. The heating dissolves the urates, and the acid dissolves the phosphates, but neither have any effect on cystin.

2. *Deposits found occasionally in alkaline urine only.*

The formation of these has already been explained at p. 262 and p. 460. They are all dissolved on adding a few drops of nitric or hydrochloric acids. They are,

(1.) *Ammoniaco-magnesian, or triple phosphate* (Plate I. fig. 18).—This salt always exists in ammoniacal urine, and is easily recognised by its well-known crystalline forms. It is usually found in variously modified six-sided crystals, some elongated (A), others nearly square (see to right of *b*), some having sharp angles, while others have broad facets (*a*), and in very alkaline urine they appear as feathery crystals (*c*).

(2.) *Phosphate of lime.*—It is usually an amorphous white powder, but occasionally it appears aggregated into rosette-like crystals.

(3.) *Urate of ammonia* is always present in alkaline, and rarely in acid urine. It has been described above.

(4.) *Urate of lime* is also occasionally found in alkaline urine.

3. *Organised deposits.*

These are mucus, blood, pus, tube casts, spermatozoids, torulæ, sarcinæ, bacteria, vibriones, &c.

(1.) *Mucus.*—When urine is left at rest, cloudy transparent floculi are seen, which consist of mucus entangling various forms of epithelial cells, derived from the urinary passages. If the supernatant liquid be carefully poured off, and acetic acid added to the mucus, it coagulates, forming delicate molecular fibres (Plate IV. fig. 1).

(2.) *Blood.*—Urine containing blood has a peculiar smoky colour that the practised eye can readily detect, but the best test is to identify the blood corpuscles by means of the microscope. As a rule, the blood corpuscles are colourless and have lost their biconcave form, and are globular from the imbibition of water. Urine containing blood always contains a trace of albumin.

(3.) *Pus.*—If there be a thickish yellow deposit at the bottom of the vessel, which has a stringy consistence, it usually consists of mucus containing pus. Pour off the supernatant fluid, and add to the deposit an equal bulk of caustic potash. It at once gelatinizes, becoming so thick and tough that it cannot be poured from the test tube. When pus is present in small quantity, by means of the microscope we can readily detect the pus corpuscles (Plate III. figs. 17 and 18).

(4.) *Tube casts.*—These bodies are detected by allowing any sediment to fall to the bottom of a conical glass, removing a small portion of it with a fine pipette, placing a drop on a slide, covering it with a thin glass, and examining it with a power of 250 diam. linear. Tube casts are of various kinds, but they may be conveniently classified under the following: *a.* Fibrinous casts, often containing blood discs; *b.* Desquamative casts, containing epithelial cells; *c.* Granular or fatty casts, containing numerous oil globules, free, or in the epithelial cells (Pl. XIII. figs. 12 and 13); *d.* Hyaline or waxy casts, solid and transparent, or containing epithelial cells, granules, and free nuclei.

(5.) *Spermatozoids, torulæ, sarcinæ, bacteria, vibriones, &c.*—These, occasionally found in urine, may all be readily detected by their characteristic microscopical appearance.

The gases of the urine are not of importance, and it is sufficient to state they are the same as those of the blood, and in variable proportion.

CLINICAL EXAMINATION OF THE URINE.

The examination of a specimen of urine is to be made in the following manner:—

1. *Colour*, whether pale from being dilute, dark from being concentrated, dark or greenish from presence of bile, smoky from blood.

2. *Smell.*—Fragrant from the existence of cystine, or sugar, &c., or fœtid from alkalinity.

3. *Measure quantity passed in 24 hours*, and observe whether there is excess or diminution.

4. *Specific gravity.*—Take the specific gravity, if possible, of the mixed urine. Normal sp. gr. 1020. If high, suspect sugar; if low, suspect albumin.

5. *Reaction.*—If acid, is it normally so or not? If excessively acid, examine for crystals of uric acid. If alkaline, ascertain whether the alkali is fixed or volatile.

6. *Heat.*—Heat a portion in a test-tube. If a precipitate appear, it may be albumin or phosphates. Add a drop or two of nitric or hydrochloric acids. If precipitate dissolve, *phosphates;* if not, *albumin.* If a deposit disappear on heating, we have *urates.* If it do not disappear,

add a drop of nitric acid. If now dissolved, we have *phosphates*; if not, *cystin*.

7. *Bile.*—Test for bile pigment and bile acids, if necessary (p. 458).

8. *Sugar.*—Test for sugar, if necessary (p. 481).

9. *Chlorides.*—Add a drop of nitric acid, and then nitrate of silver, *till a precipitate ceases to form.* Thus estimate the amount of *chlorides.*

10. *Microscope.*—Examine for blood, pus, cystin, oxalate of lime, leucin, tyrosin, tube casts, &c., by the microscope.

ANALYSIS OF THE FÆCES.

As may be expected, the constitution of this excretion varies considerably from time to time. There are always present fragments of the undigested remnants of food, fatty matter, fatty acids, bile pigment, and soluble salts, chiefly alkaline phosphates, the ammoniaco-magnesian or triple phosphate, with traces of sulphates and earthy phosphates. Undigested fragments are readily separated by suspending them in water; fatty matter may be taken up with ether and alcohol; and the ash obtained by incineration will yield the mineral ingredients. Dr Marcet states* that healthy human fæces contain an acid, *excretolic acid*, and a substance called *excretin*, both of which are soluble in ether. He obtains these substances by making an alcoholic extract of fæces. This deposits, after long standing, an "olive-coloured" acid, *excretolic acid.* The alcoholic solution is then treated with milk of lime which throws down *excretin*, with other substances. The excretin is now separated from these by ether. It is probable that these substances may not be fixed compounds. (See pp. 271–2.)

III. GENERAL QUALITATIVE EXAMINATION OF AN ANIMAL SOLID.

The analysis of tissues and organs is attended with even greater difficulty than in the case of animal fluids. It is important, if trustworthy results are desired, to operate upon at least 12 or 15 lbs. of the tissue. The following is the mode of procedure to be adopted:—†

1. Cut the tissue into small fragments, and allow it to macerate in cold water. Filter. Add to the filtrate a concentrated solution of barium hydrate to throw down *phosphates*, *sulphates*, *uric acid*, and *hypoxanthin*.

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* Marcet, Phil. Trans. 1854, p. 265; and 1857, 403.

† Watt's Dictionary of Chemistry, vol. i. p. 252.

2. Filter again and evaporate to a syrup. During this operation, a film will collect on the surface, consisting probably of *barium carbonate* or *magnesium phosphate*, and possibly of *uric acid* and *hypoxanthin.*

3. Allow crystals to separate out of the syrup, and probably they will consist of *creatin.*

4. Extract the mother liquid with alcohol and ether, and thus obtain *lactates of potash and soda*, *inosite*, *creatinin*, and *leucin.*

5. Make a fresh extract by steeping a portion of the tissue in cold water. Boil, and *albuminous matters* will coagulate, and are to be separated by filtration.

6. Evaporate the filtrate to a syrup, and masses having a crystalline appearance may separate out. These consist of *leucin. Tyrosin* sometimes appears in the form of star-shaped groups of slender needles, which are insoluble in alcohol.

7. The mother liquids from the last-mentioned deposits contain *volatile acids*, *lactic acids*, &c.

8. Incinerate a known weight of the substance, weigh the ash, dissolve it in a little hydrochloric acid, and test the solution for *inorganic acids* and *bases.*

Thus we obtain a general knowledge of the chemical constituents of the tissue under examination. Special processes are requisite for special tissues.

IV. QUALITATIVE ANALYSIS OF SPECIAL ANIMAL SOLIDS.

Under this head we shall treat of the analysis of muscle, white fibrous tissue, yellow elastic tissue, tooth, cartilage, bone, the nervous system, and lastly, of liver.

ANALYSIS OF MUSCLE.

1. *Reaction.*—When quiescent muscle is tested with litmus paper, it is found to be neutral or slightly alkaline, but if the muscle be thrown for sometime into a state of tetanus by an interrupted current of electricity, it is found to become acid. This is generally supposed to be due to the formation of sarcolactic acid.

2. *Kühne's method of obtaining muscle-plasma.*—Kill two frogs, and inject into the blood vessels a weak solution of common

salt (1 per cent.), until all blood is removed. Then cut off all the muscle of the limbs, reduce it to fragments, and subject it to powerful pressure. A liquid is thus obtained, termed by Kühne, *muscle-plasma*, which soon coagulates, resolving itself into a clot, called muscle clot or *myosin*, and a fluid, *muscle-serum*.

3. *Examination of muscle-serum.*—If this fluid be obtained in sufficient quantity, it will be found to contain three modifications of albumin, each coagulating at a different temperature. When a portion of muscle-serum is heated to 30° C. a coagulation takes place ; increase the heat to 45° C. and there is a further coagulation ; continue heating until 75° C. and another large amount of albumin will fall down. Muscle-serum also contains many excrementitious substances, resulting from the retrograde change of the tissues (*Secondary Digestion*, p. 239), such as creatin, creatinin, leucin, tyrosin, urea, uric acid, &c. These are to be distinguished and separated by the special processes and tests already fully described.

4. *Examination of muscle-clot or myosin* (p. 10).—This will be found to be insoluble in water, ether, or alcohol, but it is very soluble in dilute acids or dilute alkalies, and especially so in a ten per cent. solution of common salt. If the common salt solution be added to distilled water, the myosin falls as a flaky precipitate.

5. *Syntonin* (p. 10).—Dissolve a portion of muscle-clot in a little weak hydrochloric acid. When this acid solution is added to water, a flaky precipitate is obtained, which is insoluble in a ten per cent. solution of common salt. This substance, which thus does not exhibit the characteristic reaction of myosin, has been termed by Kühne *Syntonin*. He holds that syntonin does not exist as such in muscle, but is an artificial product obtained by the action of dilute acid on myosin. Syntonin may be prepared from muscle in the following way :—Mince a piece of muscle and allow it to macerate in cold water until the water does not coagulate on boiling, shewing the absence of albumin. The macerated muscle is now treated with ten times its bulk of weak hydrochloric acid (·1 per cent.) and left to stand for 24 hours. Neutralise with carbonate of soda, and a white and gelatinous precipitate will fall, consisting of syntonin.

6. *Inosite.*—The muscular substance of the heart contains a peculiar saccharine substance, isomeric with glucose, $C_6H_{12}O_6$,

which may be separated as follows:—Macerate the heart in water, precipitate the phosphates with baryta-water, filter, evaporate the filtrate, and allow creatin to separate out. Treat the mother liquid with dilute sulphuric acid, which will precipitate the baryta. Filter so as to remove the sulphate of barium. Shake up the liquid with ether so long as anything is dissolved. Separate the ether by skimming, and mix with alcohol until a precipitate appears. This precipitate is sulphate of potash, which is now separated by carefully pouring off the supernatant fluid. Mix this latter with more alcohol, and soon small oblique or tabular prisms of inosite will separate (p. 27).

Scherer's test for inosite.[*]—The following is a test for the presence of inosite. To an aqueous solution, evaporated nearly to dryness, add a drop or two of nitric acid, moisten the residue with a few drops of ammonia and calcium chloride, again evaporate, and a rose-coloured substance remains.

Incineration—Incinerate a given weight of muscle, and weigh the ash. Dissolve this in hydrochloric acid, and test for salts in the ordinary way.[†]

ANALYSIS OF WHITE FIBROUS TISSUE.

1. *Basis of white fibrous tissue, gelatin.*—This tissue shrinks much on being dried. When allowed to macerate in water, or when boiled in water, a gelatinous mass is obtained, consisting of gelatin (p. 10). The jelly dissolves in hot water, and from the solution, alcohol precipitates a white clotted mass.

2. *Incineration.*—White fibrous tissue contains a very small amount of inorganic matter, which can be obtained by incineration.

ANALYSIS OF YELLOW ELASTIC TISSUE.

1. *Basis of yellow elastic tissue, elastin.*—Boil a piece of the *ligamentum nuchæ* of an ox with alcohol, then with water containing ten per cent. of strong hydrochloric acid; allow it to cool, and a yellowish, fibrous, and brittle mass is obtained, termed elastin. This substance is insoluble in water, alcohol, ether, and acetic acid. It is dissolved by strong caustic potash.

2. *Incineration.*—There are more inorganic substances present

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[*] Scherer, Ann. Ch. Pharm., lxiii. 322, lxxxi. 375.

[†] For details as to the chemical composition of "Flesh," or butcher meat, see Watt's Dictionary of Chemistry, vol. ii. p. 661.

in elastic tissue than in white fibrous tissue. The amount of these may be determined by incineration.

ANALYSIS OF TOOTH.

1. *Separation of organic basis.*—By allowing fragments of teeth to macerate for three or four weeks in dilute hydrochloric acid (1 to 19 of water), a soft substance remains, which is probably gelatin. This constitutes the organic basis of teeth, and is present in larger quantity in dentine than in enamel.

2. *Incineration.*—By incinerating teeth, the organic matter is burnt off, and the ash will be found to consist chiefly of calcium phosphate, along with a much smaller quantity of calcium carbonate. Phosphate of magnesia, and a very minute trace of calcium fluoride, are also present. For examples of analyses of teeth, see p. 87.

ANALYSIS OF CARTILAGE AND BONE.

1. *Water in cartilage.*—Weigh a piece of cartilage, allow it to dry in a hot-air chamber, and it will be found to have lost half its original weight. This is owing to the fact that cartilage consists largely of water.

2. *Preparation of chondrin* (p. 11).—Boil a few of the cartilages of the ribs or joints with water for 48 hours, evaporate to a jelly, and wash the jelly with ether to free it from fat. The jelly is chondrin. The various reactions of chondrin may now be demonstrated. It is soluble in boiling water, but insoluble in alcohol or ether. When any of the mineral acids are added to an aqueous solution, a precipitate is formed, which is redissolved in excess; but the precipitate formed by carbonic, sulphurous, acetic, or tartaric acids, is not redissolved in excess. It should also be compared with gelatin, as follows:—

Reagent.	Chondrin.	Gelatin.
Alum.	Precipitate.	No precipitate.
Acetate of lead.	Precipitate.	No precipitate.
Sulphate of iron.	Precipitate.	No precipitate.
Mercuric chloride.	No precipitate.	Precipitate.

3. *Bone. Organic basis of bone, ossein.*—Allow fragments of bone to macerate for some time in dilute hydrochloric acid (1 to 19 of water). The calcium salts are dissolved, and a soft translucent mass remains, termed bone-cartilage or *ossein.* This substance resembles gelatin, but it differs from it in being

insoluble in boiling water. By prolonged boiling, however, ossein is converted into gelatin.

4. *Inorganic salts of bone.*—The acid solution of bone salts may now be evaporated, and the examination of these inorganic salts conducted in the usual method.

5. *Incineration.*—First reduce the bone to fine powder, wash with water to remove soluble salts, and with ether to remove fat. The powder is now incinerated (best of all in a muffle) till it becomes white. A few drops of solution of carbonate of ammonia are now added to it to make up for the loss of any carbonic acid driven off from the carbonate of lime present in bone, and it is again incinerated. The difference between the weights before and after ignition gives the amount of ossein. The ash is now to be analysed in the ordinary way.

The results of numerous analyses of cartilage and bone will be found at pp. 90, 92, 93.*

ANALYSIS OF THE NERVOUS SYSTEM.

The chemical composition of nervous tissue is still very imperfectly understood, and no definite mode of chemical analysis can be recommended.

1. *Water and fat.*—The amount of water may be ascertained by drying a certain definite weight, and will be represented by the loss in weight. The white matter of the nervous centres contains less water than the grey matter ; while the white, on the other hand, contains more fat than the grey matter. The amount of fat may be determined by acting upon nervous substances with ether.

Various physiological chemists have detected in nervous matter the following substances : leucin, uric acid, xanthin, inosite, creatin, creatinin, formic, and acetic acids.

2. *Cerebric acid.*—This is a fatty acid supposed to exist in the brain. Cut brain substance into thin slices, act upon it with boiling alcohol to remove water, press it, digest with cold, then with warm ether, distil off the ether, and digest with much more ether. We have now cerebrate of soda mixed with phosphate of lime, &c. Digest it in boiling absolute alcohol acidulated with sulphuric acid. We thus obtain an alcoholic solution of cerebric acid. When this is evaporated, the acid is deposited

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* For analyses of bones of different animals, see article "Bone" in Watt's Dictionary of Chemistry, vol. i. page 619.

as a white crystalline substance. It is doubtful if this acid be a constant ingredient, and probably it is a substance produced artificially during the chemical process. Other substances have been found in brain, termed cerebrin, cerebrol, and cerebrote; but it is probable they are one and the same substance.

3. *Protagon.*—This is the name of a substance supposed to exist in brain. According to Liebreich, it is the principal constituent of nervous tissue. (*a.*) Reduce brain substance to a pulp, and act upon this with water and ether at 0° C. From the remaining substance extract the protagon by 85 per cent. alcohol at 45°. Cool the alcoholic solution to 0° C., and a precipitate is formed which, on being examined microscopically, is found to consist of bundles of crystals.

(*b.*) This substance may also be prepared in a somewhat different form from yoke of egg. Beat up very thoroughly the yoke of an egg in 2 ounces of absolute alcohol. Boil carefully and filter while hot. Allow the filtrate to drop upon a flat and cold porcelain plate, when a yellowish non-crystalline deposit will be found, consisting of protagon. The remarkable reactions of this substance are described at page 45.

4. *Oleo-phosphoric acid.*—This is a fatty acid found in the brain; it may be prepared as follows:—Beat up brain substance to a thin pulp with water, heat the mixture to the boiling point, and act on the coagulum formed with boiling alcohol. This extract is filtered while hot, and deposits cholestrin, cerebrin, and oleo-phosphoric acid, united with alkalies. Act upon this with cold ether, which takes up oleo-phosphate of soda. Evaporate the ethereal solution, decompose the oleo-phosphate by a few drops of dilute hydrochloric acid, dissolve the residue in boiling alcohol, and the oleo-phosphoric acid is deposited when it cools. It is a gummy or fatty yellowish substance, easily decomposed into phosphoric acid, and one of the higher fatty acids.

Analysis of the Liver.

It is well known that the liver contains a substance termed *glycogen*, isomeric with starch, $C_6H_{10}O_5$ (p. 25). It may be prepared from the liver, as follows: *Bernard's method.*—Cut a piece of liver into small portions, boil it for an hour in water, and allow the hot decoction to filter into glacial acetic acid. Nearly pure glycogen is thrown down, the albuminous substances remaining in solution. It is precipitated from its aqueous solution by animal charcoal, and is usually quite insoluble in alcohol. It is important to observe that dilute mineral acids, diastase, and the peculiar nitrogenous ferments found in the blood, saliva, liver, and pancreas, readily convert glycogen into diabetic sugar, $C_6H_{12}O_6$. It is probable a change of this kind occurs with great rapidity on death, for we have found that a decoction of a liver removed from a rabbit or mouse just killed, always gives a characteristic reaction with any of the tests for sugar. If, however, a portion of the same liver be kept for several hours, and a decoction then made, a much more decided reaction will be obtained. (See p. 251.)

In conclusion, it may safely be asserted that chemical physiology is still in its infancy. It is a difficult field of labour, both from the complex constitution, as well as from the instability of many of the substances to be examined. Nor must we forget that the chemist can analyse only dead tissues and fluids, not living tissues, and many of the substances which are obtained by chemical processes in the laboratory do not exist as such in the living body.

PRACTICAL HISTOLOGICAL PHYSIOLOGY.

This subject can only be prosecuted with the aid of an achromatic microscope, the construction and mode of employment of which instrument must be first understood.

History of the Microscope.

A microscope (from *μικϱὸς*, small, and *σκωπέω*, to see) may be defined, an instrument which is capable of making small objects appear larger than they do to the naked eye. In this sense, it applies to any instrument, of whatever contrivance, capable of fulfilling this condition ; and if we accept this definition, various reasons have been adduced to shew that the microscope was known to the ancients. Spectacles, it is said, were in use among the Greeks and Romans ; and as the glasses of these were made of different convexities, and, consequently, of different magnifying powers, it is natural to suppose that they must have been acquainted with the property possessed by the lens, of enlarging small objects. Various passages also occur in the works of

Jamblichus, Pliny, Plutarch, Seneca, and others, which lead to a similar conclusion. Thus, Seneca observes: "Letters, though minute and obscure, appear larger and clearer through a glass bubble filled with water." Now, this glass bubble filled with water is sold by pedlars and others to the vulgar at the present time, in order to magnify objects.

The compound microscope appears to have been constructed in the early part of the seventeenth century. Both Holland and Italy have claimed the honour of producing its inventor. William Borelli attributes its construction to one Zacharias Jansen of Middleburgh in the Low Countries, who, with his son John, according to this author, made his first compound microscope so early as 1590. It is stated that either he or his son presented one of his instruments to the Archduke Charles of Austria, who, in turn, gave it to Cornelius Drebbel, a Dutch alchemist, who subsequently became astronomer to James I. of England. He it was who first brought the instrument to London in 1619, where it was seen by William Borelli and other scientific individuals. It is well known that Drebbel made microscopes in London in 1621, and generally passed for their inventor.

On the other hand, Francis Fontana, a Neapolitan, states, that he invented the instrument in 1618, and gave a description of it in his "Novæ terrestrium et cælestium observationes." It would appear, however, that although Drebbel and Fontana disputed concerning the origin of this instrument, the honour of inventing it, so far as our present knowledge extends, belongs to Jansen.

The microscope brought by Drebbel to London is thus described by Adams, who observes: "It is possible that this instrument of Drebbel's was not strictly what is now meant by a microscope, but was rather a kind of microscopic telescope, something similar in principle to that lately described by Mr Æpinus in a letter to the Academy of Sciences at Petersburgh. It was formed of a copper tube, six feet long, and one inch in diameter, supported by three brass pillars in the shape of dolphins. These were fixed to a base of ebony, on which the objects to be viewed by the microsope were also placed."*

The improvement of the microscope made much less rapid progress than that of the telescope. The great utility of the latter, indeed, appears to have been early appreciated, while the microscope was for a long time only regarded as a means of satisfying curiosity. Thus it was merely looked upon as an expensive toy, and kept by the rich in their cabinets as a source of amusement. At a later period, however, it was found susceptible of adding much to our knowledge of the natural sciences ; and no sooner was this perceived, than the most celebrated artists, mechanics, geometricians, and natural philosophers paid great attention to its improvement. For a long time, however, they were baffled by the difficulties of the undertaking, and during this period naturalists, for the most part, employed the simple microscope. Thus, some of the most important discoveries in science have been made by means of a single biconvex lens, and the laborious and brilliant researches of Leuwenhoeck, Swammerdam, Lyonet, Ellis, and others were thus accomplished.

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* Adams on the Microscope, p. 3.

The inconveniences of the simple microscope, however, are considerable. Thus, when capable of magnifying largely, the field of vision is very limited, and there is great difficulty in adjusting the focus. Leuwenhoeck had a separate lens especially adapted to one or two objects, and always had several hundreds at his disposal.

The imperfections of the compound microscope, on the other hand, were at that time very great, and must have appeared insurmountable. Thus, from its peculiar construction, the rays of light were readily decomposed, and circles of different colours surrounded or tinged the object, constituting the aberration of refrangibility. The form of the object was also distorted on account of the aberration of sphericity. Opaque objects could not be seen from the absence of light, and very transparent ones could not be examined from its excess.

But gradually all these different obstacles were overcome by patience and labour. The details connected with these, however, we cannot enter into. Suffice it to say, that to Lieberkühn we are indebted for the means of examining opaque objects by means of a reflector ; to the diaphragm of Le Baillif, for a convenient mode of modifying an excess of light. Achromatic instruments were constructed principally through the ingenuity and labours of Euler, Dolland, Frauenhofer, Selligue, Amici, Tulley, and Vincent, and Charles Chevalier, and may be said to have been perfected only during the last thirty years.

The object of the optician at present engaged in manufacturing this instrument is to construct a microscope which will admit of an easy and universal application, and possess the power of magnifying largely, combined with clearness and distinctness of the image. The instruments now constructed by Ploesel in Vienna, Frauenhofer in Munich, Schiek of Berlin, Hartnach and Nachet in Paris, and Powell, Ross, and Smith in London, if they have not reached perfection, certainly approach very near it, and permit the most minute details of structure to be examined with ease, even when magnified largely.*

OPTICAL PRINCIPLES ON WHICH THE MICROSCOPE IS CONSTRUCTED.

The optical principle on which every microscope is constructed is, that rays of light passing through a lens are more or less refracted, that is, are bent out of the straight line. This has already been fully explained at page 135.

Theory of enlargement.—The theory of a simple bi-convex lens will be understood by referring to Plate XXI. fig. 3. Here we have a convex lens interposed between the eye and a small object $a\ b$. If $a\ b$ be very close to the eye, the rays passing from it would diverge so far that the optical arrangements of the eye itself would fail to bring them to a focus on the retina, because the eye is adapted to receive and bring to a focus rays which are parallel or but slightly divergent. But when the lens $x\ y$ is placed between the eye and the object, the rays $a\ x$, $b\ y$, are so refracted by the lens as to come to a focus on the retina. Thus a well-defined picture or image is formed. But the rays now enter the eye at a greatly increased angle, and, consequently, the small object $a\ b$ appears increased in size to $a'\ b'$. It will be evident also, that if the lens $x\ y$ were more convex the effect would be further increased, as the refraction would be greater, and the object $a\ b$ would be seen still larger than $a'\ b'$.

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* To no one is science more deeply indebted than to the late Mr Oberhæuser of Paris. He it was who first made good microscopes *cheap*, and brought them within the reach of the poorest scientific cultivator. Thousands of his instruments have been scattered over the world, and by their aid most of the facts on which the science of histology is founded were discovered. His nephew, M. Hartnach, continues his system with the like success.

A simple lens is termed a *simple microscope.* The same theory applies to increased convexity of the lenses in the eye-piece, only it is the image which is transmitted by the objective (p. 507) that is then magnified. It follows that any imperfection it possesses will be magnified also, so that the excellence of the objective is always the chief consideration in obtaining magnifying power. A third method of obtaining enlargement is by elongation of the tube, which, by causing greater divergence of the rays, also increases the apparent size of the object.

Faults of simple lenses and their corrections.—Every simple lens has two faults or optical imperfections—1st, that of spherical aberration, and 2nd, that of chromatic aberration. The modes of remedying these faults cannot be understood without an acquaintance with their causes.

Spherical aberration. (See p. 137.)—By referring to Plate XXI. fig. 4, it will be seen that all the rays of light passing through a convex lens do not come to the same focus in consequence of the refraction being necessarily greater at the circumference than towards the centre. Thus the rays *a* and *c*, as they impinge upon the glass at a greater angle, come to a focus at A, while the rays *b*, which are nearer the centre, come to a focus at B. This is owing to the unequal refraction of the rays, the rays *a* and *b*, passing through the margin of the lens being more refracted than those of *b* passing through its centre. Consequently, an image formed on the retina either at A or B would not only be indistinct and imperfect, but curved according to the convexity of the lens. There are various methods adopted for correcting spherical aberration.

1. By using a double convex lens the radii of which are as 1 to 6, with its most convex face turned towards the object.

2. By using a stop in the eye-piece, which is a plate with a round aperture interposed between the lens and the eye (Fig. 1, *c*), so as to cut off the rays *a c* (Fig. 4), and receive only those coming from *b*. Such an arrangement is used in all compound microscopes.

3. By using combinations of lenses, so disposed that the aberration of the one will correct the aberration of the other. Thus the aberration of one plano-concave lens may be made to correct that of another, so that all the rays will be brought to one focus, as in the eye-piece of Huyghens. This arrangement

will be described after we have considered the other imperfection of simple lenses, namely :

Chromatic aberration.—When an object is examined by a simple lens it will be found surrounded by rings of colour—red, orange, yellow, and so on. This appearance arises from the fact that the lens acts as a prism (see p. 140), and decomposes or disperses the ray of white light into its constituent coloured rays—red, orange, yellow, green, blue, purple, and violet. The most refrangible of these rays are the violet, the least the red, while those between these two colours possess different degrees of refrangibility. On referring to Plate XXI. fig 2, it will be seen that the rays of white light $a\ x$ and $c\ y$ are decomposed into the violet coloured rays x A and y A, and into the red rays x T and y T, the intermediate coloured rays, purple, blue, green, yellow, and orange not being represented in the diagram. In consequence of the great refrangibility of the violet rays, they are brought to a focus at A, while the least refrangible rays, the red, meet at T, a point farther from the lens than A. If the retina were situated at A, a coloured image would be seen, the centre violet, then purple, blue, green, yellow, and orange, while the margin would be red. On the other hand, if the retina were at T, a coloured image having the centre red and the margin violet would be the result. These fringes of colour seriously interfere with a correct interpretation of microscopic appearances, and must be got rid of. This is effected

1. *By the compound acromatic lens.*—This consists essentially of a bi-convex lens of crown glass and a plano-concave lens of flint glass carefully adjusted and cemented together, as seen in Pl. XXI. fig. 1, *e*, *f*, *g*, and figs. 5, *a*, and 6. The principle is, that as the dispersive power of the flint glass is so much greater than that of the crown glass, the one exactly corrects the other, and we thus have dispersion destroyed without destroying the refraction. When this is accomplished, we have *achromatism*, or the refraction of light without decomposition. At the same time, the refractive power of the two kinds of glass being also so different as exactly to neutralise each other's defects, we remove spherical aberration by this arrangement of lenses, and we thus obtain a distinct image on the retina by all the rays being brought to a focus without dispersion. It has been found best to use a combination of three such double lenses, Fig. 1, *e*, *f*, *g*, and Fig. 5, *a*. In Hartnach's and Nachet's microscopes, each pair of these are

fitted into small rings of brass which are screwed the one before the other. In the objectives of the London makers, a section of one of which is shewn (Plate XXI. fig. 6), the front pair can be approximated to the other two pairs, or the distance between increased so as to adjust the lenses for examining objects with or without a covering glass.

Object glasses having this adjustment, are constructed as follows (Plate XXI. fig. 6). The two higher achromatic lenses are fixed in the end of the tube B; upon this slides a cylinder AA, carrying at the lower end a third lens, which, by turning the screwed ring CC, may be approximated to, or separated from, the other two lenses. These lenses can thus be so adjusted that the positive aberration of the anterior lens corrects the negative aberration of the two posterior, and also the aberration produced by even a thin covering glass when one is used. This improvement we owe to Mr Ross, the eminent optician of London.

2. *The eye-piece of Huyghens.*—It consists (Pl. XXI. fig. 1, *c c*, *b d*) of two plano-convex lenses, *b d*, with their plane sides towards the eye. These are placed, with regard to each other, at a distance equal to half the sum of their focal lengths. The upper one, *b*, is termed the *eye-glass*, the lower, *d*, the *field glass.* A stop or diaphragm is placed at *c c* in the visual focus of the eye-glass, which is the same position as that where the image produced by the field-glass *d* is formed. Huyghens made this arrangement of lenses to correct spherical aberration merely; but Boscovitch shewed that it also corrected chromatic aberration. This correction is now completely attained in all good Huyghenian eye-pieces. The rays of light passing into the eye-piece by the margin of the convex surface of the field-glass *d*, are decomposed so as to form two coloured images near the position of the eye-glass, the upper one blue and the lower red. The eye-glass, in its turn, would then magnify these so as to produce two secondary-coloured images near *y x*. These coloured images are combined so as to form a colourless image *y x*: 1st, by using a stop *c c*, which intercepts the rays passing through the margin of the lens; and 2d, by having the eye-glass slightly over corrected for chromatic aberration, so that its focus would be shorter for blue rays than for red rays by just the difference in the place of the images formed at *y x*. Thus the rays enter the eye through the eye-glass in a parallel direction, and produce a picture free from colour.

Arrangement of lenses.—A section of a compound microscope is seen in Plate XXI. fig. 1. At the lower end of the tube there are one or more combinations of achromatic lenses, termed the *objective*, *e*, *f*, *g*, and at the other the eye-piece, *c c*, *b d*. An inverted image of *x y*, a small object placed under the objective, is made and inverted in the tube of the microscope in front of *d*, the field-glass; this image is magnified and again inverted by *d*, so as to form an image beneath *b*, the eye-glass, which last image is a third time inverted by the eye-glass *b*, which also directs the rays of light into the eye *a*, so as to form a distinct image on the retina. Thus the image on the retina is reversed as regards the object, a fact to be remembered in making microscopical observations.

Modes of increasing magnifying power.—This may be done in one or more of three ways: 1st, by increasing the length of the tube; 2d, by increasing the power of the eye-piece; and 3d, by using a higher objective. The objection common to all of these arrangements is, that while we increase the power we lose light. In the first instance we lose light by distributing it over a greater length of tube; in the second, we find that while we gain in power we lose brightness and definition, because any faults of the lens are of course intensified by the eye-piece. By using higher objectives, if they are good we obtain clearness of definition, with a sacrifice of light by dispersion of the rays. This, however, can be diminished by illumination, so constructing the lenses as to permit the passage of a large amount of light. Such a lens is said to have a large angle of aperture. (See Fig. 5^a, where *a b c* is the angle of aperture.)

All three modes of enlargement, viz., by the objective, by the eye-piece, and by elongation of the tube, are taken advantage of in the best instruments, and are useful within certain limits, as in the model I recommend, now manufactured by Hartnach.

Construction of the Microscope.

A microscope may be divided into mechanical and optical parts.

Mechanical parts.—These determine its general form and appearance. Of the numerous models which have been invented, the one figured (Pl. XXI. fig. 8), one-eighth its real size, appears to me the most useful for all the purposes of the physiologist and medical practitioner. It was suggested by me to the late Mr

Oberhæuser, and manufactured by him with his accustomed ingenuity. (*b*.) The body consists of a telescope tube, eight inches in length, held by a split tube (*c*), three inches long. It may be elevated and depressed with great readiness with a cork-screw movement, communicated to it by the hand, and this constitutes the coarse adjustment. It is attached to a cross bar and pillar, at the lower portion of which last, very conveniently placed for the hand of the observer, is the fine adjustment (*f*). The stage (*d*) is three inches broad, and two and a half inches deep, strong and solid, with a circular diaphragm below it. The height enables the observer to rest his two hands edge-ways on each side, and to manipulate objects on its surface with the thumbs and fore fingers. The base of the instrument is heavily loaded with lead to give it the necessary steadiness.

This form of microscope possesses all the mechanical qualities required in such an instrument. These are—1st, steadiness; 2d, power of easy adjustment; 3d, facility for observation and demonstration; and 4th, portability.

1. *Steadiness.*—It must be evident that if the stage of the microscope possesses any sensible vibration, minute objects, when magnified highly, so far from being stationary, may be thrown altogether out of the field of view. Nothing contributes more to the comfort of an observer than this quality of a microscope, and great pains have been taken to produce it. In the large London instruments this end has been admirably attained (Plate XXI. fig. 7), but at so much cost and increase of bulk as to render it almost useless. In the small model I have recommended, all the steadiness required is present in the most convenient form.

2. *Power of easy adjustment.*—It is a matter of great importance to those who use the instrument much, and work with it for hours together, that the adjustments should work easily and rapidly, and be placed in convenient situations. Nothing can be more commodious than the manner in which these ends are arrived at in the model figured. By insertion of the body of the instrument (*b*) within a split tube (*c*), you may, by a spiral movement, elevate and depress it with the greatest rapidity, and even remove it altogether if necessary. The necessity of continually turning the large screws affixed to most microscopes (Fig. 7, D), becomes fatiguing in the extreme. Then the fine adjustment (*f*) placed conveniently behind the microscope,

near the hand which rests on the table, is in the very best position; whereas, in some London instruments, it is placed on the top of the pillar, so that you must raise your hand and arm every time it is touched (Fig 7, F). In other London instruments, it is placed in front of the body, so that you must stretch out the arm and twist the wrist to get at it. No one could work long with so inconvenient a contrivance.

3. *Facility for observation and demonstration.*—For facility of observation and demonstration, it is necessary that the instrument should be of a convenient height, and that the stage on which the objects are placed should be easily accessible. Here, again, nothing can be more commodious than the microscope I have recommended, for, when it is placed on the table, its height is almost on a level with the eye, and we can look through it for hours without the slightest fatigue. On the other hand, the stage (*d*) is elevated just so much as enables the two hands, resting on their external edges, to manipulate with facility all kinds of objects placed upon it. The large London instruments are so high as to render it necessary to stand up to see through them. To obviate this disadvantage, a movement is given to the body, by which it can be depressed to any angle (Plate XXI. fig. 7). But this movement renders the stage oblique, and removes it to a distance, where it becomes very inconvenient to manipulate on its surface. To obviate this difficulty, the stage itself has been rendered moveable in various ways by different screws (Fig. 7), so that in this way complexity has been added to complexity, until a mass of brass work and screws is accumulated, to the advantage of the optician, but to the perplexity and fatigue of the observer. But by no contrivance is it possible to avoid the aching arms which such a position of the stage invariably produces in those who work with such a cumbrous machine for any length of time. Hartnach has recently placed a joint on his small microscopes, which, when they are bent, brings the eye-piece opposite the observer's stomach. Except for the purpose of drawing with a camera it is utterly useless.

4. *Portability.*—This is a property which should by no means be overlooked in instruments that are intended more for utility than ornament. A medical man is often called upon to verify facts in various places; at his own house, at an hospital, at the bed-side of his patient, or at a private post-mortem examination. It is under such circumstances that the value of portability is

recognised. The large London instruments require an equipage or a porter to transport them from place to place ; even the putting them in and out of the large boxes or cabinets that are built around them, is a matter of labour. In short, notwithstanding the splendour of the screws, the glittering of the brass, and the fine workmanship (Plate XXI. fig. 7), there can be little doubt that, on the whole, they are very clumsy affairs.

There are many occasions on which a medical man may find it useful to carry a microscope with him, especially in the case of post-mortem examinations. Many attempts have been made to construct a pocket microscope ; and for the purposes above alluded to, I myself caused one to be constructed some years ago which, with its case, resembled a small pocket telescope. Dr Gruby of Paris, however, has planned the most ingenious instrument of this kind, which possesses most of the properties we have enumerated, and will be found very useful for those accustomed to microscopic manipulation. It is contained in a case the size of an ordinary snuff-box, and possesses all the conveniences of the larger instruments, with various lenses, a micrometer, slips of glass, needle, knife, and forceps in that small compass.* It is deficient in steadiness, however, a fault which has been removed by a similar instrument made by Nachet of Paris, the box of which is made of brass (Plate XXI. figs. 9 and 10), and which I can strongly recommend for its usefulness and excellence.

There is a general feeling among the public that the larger a microscope is, the more it must magnify ; but this is an error. A very imposing mass of brass work and mechanical complexity is no guarantee that you will see objects better, or what is of more consequence, become good observers. On the contrary, the more unwieldy the instrument, the less disposed will you be to use it. Besides, the habitual employment of artificial methods of moving about the object, as by the screws of a moveable stage, will prevent your acquiring that dexterous use of your fingers and accuracy of manipulation which are at all times so useful. Nothing, indeed, can be more amusing than to see a man twisting his screws, pushing his heavy awkward stage about, and laboriously wasting time to find a minute object which another can do in a moment, and without fatigue, by the simple use of his fingers. But perhaps you will consider the weightiest objection to the large instruments is the expense they necessitate,—the cost being necessarily in proportion to the amount of brass and mechanical labour employed upon them. If, then, you have to choose between a complex model and a simple one, I strongly advise you, as a matter of real economy, to choose the latter.

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* For a representation of this instrument, see my Clinical Medicine, fifth edition, pp. 97 and 80.

We have next to speak of the optical parts of microscopes, which are certainly much more important than the mechanical ones—for everything depends upon obtaining a clear and distinct image of the object examined. Under this head we may describe the objective, the eye-piece, and methods of illumination.

1. *The Objective, or series of Achromatic Lenses*, is that part of the optical portion of a microscope which is placed at the bottom of the tube or body, and is near the object to be examined. This may be considered the most important part of the instrument, and the greatest pains have been taken by all opticians in the manufacture of good lenses. It is here, I consider, that the London opticians are pre-eminent, for I am not aware that in any part of the world more perfect objectives have been manufactured than the eighth of an inch by Smith, the twelfth of an inch by Ross, and the sixteenth of an inch by Powell. The latter has also manufactured the twenty-fifth of an inch, which I have used with advantage. And Dr Beale tells us he has made for him a lense of one-fiftieth of an inch focus. But when we come down to one-fourth of an inch, which is by far the most useful objective for histological and medical purposes, the superiority of the London opticians is very slight, if any. At this magnifying power the compound lenses of Hartnach and Nachet of Paris ; Schiek and Pistor of Berlin ; Frauenhofer of Munich, and Ploesel of Vienna, may be employed with the greatest confidence, and it may be said that by far the largest number of important discoveries in science have been made through their employment. The Parisian lenses in addition, have one great advantage, namely, their cheapness.

The London opticians have succeeded in combining the lenses of their objectives so as to obtain a large field of vision, with as little loss of light as possible (Plate XXI. figs. 5, *a*, and 6). These qualities are valuable in the lower magnifying lenses during the examination of opaque objects, and in the higher ones when observing transparent objects by transmitted light. But in the lenses of medium power, such as the one-fourth of an inch, those of Hartnach and of other continental makers are equally good.

In recent times so-called immersion lenses have been employed with advantage, that is, lenses so made that they may be depressed in a drop of water placed upon the covering glass. The object is thereby more highly illuminated and the focal distance increased. The highest powers can in this way be obtained at a much more reasonable price, from Hartnach, than from the London makers, and they are excellent.

For the above reasons, as well as from considerable experience in the use of many kinds of microscopes by different manufacturers, I am satisfied that the best lens you can employ for ordinary purposes is Hartnach's No. 7, which corresponds to what is called in England the quarter of an inch. For low powers you may have Hartnach's No. 3, or the one-inch lens of the London opticians. For all the wants of the medical man these will be sufficent. Occasionally the higher lenses may be required by the physiologist, as during the examination of the ultimate fibrillæ of muscle. These, by whoever made, may be attached to the model we have recommended by means of a brass screw made on purpose.

2. *The Eye-piece.*—This is that portion of the optical apparatus which is placed at the upper end of the tube or body, and is near the eye of the observer (Fig. 8, *a*). While the objective magnifies the object itself, the eye-piece only magnifies the image transmitted from below. Hence, as a source of magnifying power, it is inferior to the lens; and when this possesses any defects, these are enlarged by the eye-piece. Two eye-pieces are all that is necessary with the model I have recommended, and those of Oberhæuser, called Nos. 3 and 4, are the most useful for the medical man.

3. *Methods of illumination.*—There are few things of more importance to the practical histologist than the mode of illumination. This is accomplished—1st, by transmitted light; 2d, by direct light; and 3d, by achromatic light.

Transmitted light is obtained by means of a mirror placed below the object, which, to be seen, must therefore be transparent (Plate XXI. fig. 8, *e*). In large microscopes the mirrors are provided with universal joints, so that they may easily be turned in any direction (Fig. 7, M). Below the stage every microscope should possess a diaphragm pierced with variously sized holes, whereby the amount of light furnished by the mirror may be moderated. In Oberhæuser's and Nachet's instruments the smallest aperture should be employed for the higher objective. It is also useful in the examination of many objects that the light should be directed upon them obliquely ; this may be done by the diaphragm, or by the mirror, and in the small model (Fig. 8) is admirably attained by simply turning the whole microscope. The best light for microscopic purposes is that obtained by catching the rays which are reflected from a white cloud. The conjoined use of the mirror and diaphragm can only be learned from actual experience.

Direct light is employed in the examination of opaque objects, and the lenses of low power, manufactured by the principal London opticians, enable us to do so without assistance. Occasionally, however, the light of the sun is useful; and when this cannot be obtained, the rays of a lamp or gas light, concentrated by a bull's-eye lens, may be employed (Fig. 8, *g*). Hence every microscope should be possessed of such a lens, and it is most convenient to have it attached to the body of the instrument by a moveable ring, and stem with one or two joints, as in the model figured (Plate XXI. fig. 8).

Achromatic light is only serviceable in the examination of very delicate objects, with high powers. The apparatus necessary for obtaining it is occasionally useful in ascertaining the ultimate structure of muscle, or the nature of the markings on minute scales or fossils. The most elaborate instrument for obtaining condensed and achromatic light is Gillett's condenser (Fig. 7, *g*). It can only be adapted to the large instruments, and is seldom used. In the same way I know of little benefit to be obtained by a polarising apparatus.

In addition to the mechanical and optical parts constituting the microscope itself, the box which contains it should possess a convenient place for holding a few slips of glass, a pair of small forceps, a knife, and two needles firmly set in handles. A micrometer to measure objects with is also essential to those who are making observations with a view to their exact description. No other accessories are necessary.

An excellent microscope of the model figured (Fig. 8), by Hartnach, with two objectives (Nos. 3 and 7), two eye-pieces

(Nos. 3 and 4), a neat box with all the accessories necessary (with the exception of a micrometer, which had better be English) may be obtained in Paris for the sum of 140 francs (£5 12s.), and ought not to cost in Edinburgh, after payment of carriage, more than seven pounds. Nachet's instruments are somewhat cheaper. Either of them, for all the purposes of the student, is amply sufficient.

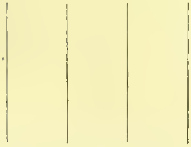
Test-objects.—The defining power of a microscope is generally tested by examining with it a transparent object, having certain fine markings, which can only be rendered clearly visible when the glasses are good. In all such cases, it is of course necessary to be familiar with the structure of the test-object in the first instance. If you are not confident on this point, it is better to trust to the judgment of a friend whose knowledge of histology is ascertained, or place your dependence entirely on a respectable optician. One of the best test-objects for a quarter of an inch lens is a drop of saliva from the mouth. For, if a microscope shews with clearness the epithelial scales, the structure of the salivary globules, their nuclei, and contained molcules, you may be satisfied that the instrument will exhibit all the facts with which, as medical men, you have to do. (See Plate IX. fig. 3.)

MENSURATION AND DEMONSTRATION.

Having obtained a good instrument, and tested its qualities in the manner described, the student should next determine the number of diameters linear the various combinations of glasses magnify. This he may do for himself with the aid of a micrometer, a pair of compasses, and a measure.

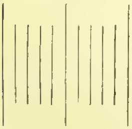
A micrometer is a piece of glass on which lines are ruled at the distance of $\frac{1}{100}$th or $\frac{1}{1000}$th of an inch. This must be placed under the instrument, when the lines and the distances between them will of course be magnified by the combination of glasses employed, like any other object. Taking a pair of compasses in one hand, we separate the points, and place them on the stage (always on a level with the micrometer magnified). Now, looking through the instrument with one eye, we regard the points of the compass with the other, and mark off by the naked sight, say the $\frac{1}{100}$th of an inch, as magnified by the instrument. Though difficult at first, a little practice enables us to do this with the greatest accuracy. The result is, that if the distance magnified and so marked off ($\frac{1}{100}$th of an inch) is equal to three inches, the instrument magnifies 300 times linear; if two inches, 200 times; and so on.

To measure the size of objects, they may be placed directly on the micrometer; but as this is at all times inconvenient, whilst the object and micrometer, from their not being in the same plane, cannot, under high powers, both be brought into focus at once, it is better to use an eye-micrometer. Many ingenious inventions of this kind are to be procured. The most simple is a ruled micrometer placed in the focus of the upper glass of the eye-piece. With this we observe how many divisions of the eye-micrometer correspond with one of those magnified by the microscope, always making our observation in the centre of the field, where the aberration of sphericity is least. On the latter being removed and replaced by an object, it becomes a matter of mere calculation to determine its size. Thus, supposing each of the spaces in the upper to represent the $\frac{1}{1000}$th of an inch magnified 250 diameters linear, and five of the lower spaces, as seen in an eye-micrometer, to correspond with one of these—it follows that each of these latter must measure $\frac{1}{5000}$th of an inch.



Spaces equal to 1-1000th of an inch magnified 250 diameters linear.

If it be not in your power to estimate the magnifying power for yourself, the optician will construct a table, setting forth the various degrees of enlargement possessed by the lenses, and different eye-pieces with the tube up or down. This table should always be referred to during the description of objects, and the amount of magnifying power invariably stated.



Five ruled spaces in an eye-micrometer, corresponding to one of those above, and consequently equal to the 1-5000th of an inch.

The art of demonstrating under the microscope is only to be acquired by long practice, and like everything requiring practical skill, cannot be learnt from books or systematic lectures. I can only here give very general directions on this head.

All that is necessary in examining fluid substances, is to place a drop in the centre of a slip of glass, and letting a smaller and thinner piece of glass fall gently upon it, so as to exclude air bubbles, place it upon the stage under the objective. In this way the fluid substance will be diffused equally over a flat surface, and evaporation prevented, which would dim the objective. The illumination must now be carefully arranged, and the focus obtained, first by means of the coarse, and then by means of the fine, adjustment. It will save much time, in examining structures, to employ always, at one sitting, the same slips of glass, as it is easier to clean these with a towel, after dipping them in water, than to be perpetually shifting the coarse adjustment.

The action of water, acetic acid, and of other re-agents, on the particles contained in a fluid, may be observed by mixing with it a drop of the re-agent before covering with the upper glass ; or if this be already done, the drop of re-agent may be placed at the edge of the upper glass, when it will be diffused through the fluid under examination by imbibition.

The mode of demonstrating solid substances will vary according as they are soft or hard, cellular or fibrous. The structure of a soft tissue, such as the kidneys, skin, cartilage, &c., is determined by making very minute, thin, and transparent slices of it in various directions, by means of a sharp knife or razor. These sections should be laid upon a slip of glass, then covered over, and slightly pressed flat, by means of an upper one. The addition of a drop of water renders the parts more clear, and facilitates the examination, although it should never be forgotten that most cell-structures are thereby enlarged or altered in shape from endosmosis. Acid and other re-agents may be applied in like manner. The double-bladed knife of Valentin will enable us to obtain large, thin, and equable sections of such tissues, and permit us to see the manner in which the various elements they contain are arranged with regard to each other. Harder tissues, such as wood, horn, indurated cuticle, &c., may also be examined after making thin sections of them. Very dense tissues, such as bone, teeth, shell, &c., require to be cut into thin sections, and afterwards ground down to the necessary thinness. Preparations of this kind are now manufactured on a large scale, and may be obtained at a trifling cost. A cellular parenchymatous structure, such as the liver, may be examined by crushing a minute portion between two glasses. If it be membranous, as the cuticle of plants, epithelial layers, &c., the membrane should be carefully laid flat upon the lower glass, and covered with an upper one. The fibrous and tubular structures such as the areolar, elastic, muscular, and nervous tissues, must be separated by means of needles, and then spread out into a thin layer before examination, with or without water, &c.

The commencing observer should not be discouraged by the difficulties he will have to encounter in dissecting and displaying many tissues. He must remember that the figures he sees published in books are generally either fortunate or very carefully prepared specimens. Practice will soon enable him to obtain the necessary dexterity, and to convince himself of the importance of this mode of inquiry. He should early learn to draw the various objects he sees, before and after the action of re-agents, not only because such copies constitute the best notes he can keep, but because drawing necessitates a more careful and accurate examination of the objects themselves. A note-book and pencil for the purpose should be the invariable accompaniments of every microscope.

How to Observe with a Microscope.

The art of observation is at all times difficult, but is especially so with a microscope, which presents us with forms and structures concerning which we had no previous idea. Rigid and exact investigation, therefore, should be methodically cultivated from the first, in order to avoid those errors into which the tyro, when using a microscope, is particularly liable to fall. Thus, he should carefully examine the physical properties of the particles and ultimate structures he may see, and not hastily conclude that he has under observation so-called pus, tubercle, or cancer-corpuscles, because they were obtained from what was, *à priori*, believed to be pus, tubercle, or cancer. Nothing has been more clearly demonstrated by the progress of histology than the fact, that the naked sight has confounded different structures together, from a similarity of external appearance, and that the greatest caution is required at all times, but especially by learners, in forming opinions as to the nature of different tissues.

The physical characters which distinguish microscopic objects consist of—1st, Shape; 2d, Colour; 3d, Edge or border; 4th, Size; 5th, Transparency; 6th, Surface; 7th, Contents; and 8th, Effects of re-agents. These we may notice in succession.

1. *Shape.*—Accurate observation of the shape of bodies is very necessary, as many of these are distinguished by this physical property. Thus the human blood globules, presenting a biconcave round disk, are in this respect different from the oval corpuscles of the camelidæ, of birds, reptiles, and fishes. The distinction between circular and globular is very necessary to be attended to. Human blood corpuscles are circular and flat, but they become globular on the addition of water. Minute structures seen under the microscope may also be likened to the shape of well-known objects, such as that of a pear, balloon, kidney, heart, &c. &c.

2. *Colour.*—The colour of structures varies greatly, and often differs under the microscope, from what was previously conceived regarding them. Thus the coloured corpuscles of the blood, though commonly called red, are in point of fact yellow. Many objects present different colours, according to the mode of illumination ; that is, as the light is reflected from, or transmitted through, their substance, as in the case of certain scales of insects, feathers of birds, &c. Colour is often produced, modified, or lost, by re-agents, as when iodine comes in contact with starch corpuscles, when nitric acid is added to the granules of chlorophyle, or chlorine water affects the pigment cells of the choroid, and so on.

3. *Edge or border.*—The edge or border may present peculiarities which are worthy of notice. Thus, it may be dark and abrupt on the field of the microscope, or so fine as to be scarcely visible. It may be smooth, irregular, serrated, beaded, &c. &c.

4. *Size.*—The size of the minute bodies, fibres, or tubes, which are found in the various textures of animals, can only be determined with exactitude by actual measurement, in the manner formerly described. It will be observed for the most part, that these minute structures vary in diameter, so that when their medium size cannot be determined, the variations in size from the smaller to the larger should be stated. Human blood globules in a state of health have a pretty general medium size, and these may consequently be taken as a standard with advantage, and bodies may be described as being two, three, or more times larger than this structure.

5. *Transparency.*—This visible property varies greatly in the ultimate elements of numerous textures. Some corpuscles are quite diaphanous, others are more or less opaque. The opacity

may depend upon corrugation or irregularities on the external surface, or upon contents of different kinds. Some bodies are so opaque as to prevent the transmission of the rays of light, when they look black by transmitted light, although they be white, seen by reflected light. Others, such as fatty particles and oil globules, refract the rays of light strongly, and present a peculiar luminous appearance.

6. *Surface.*—Many textures, especially laminated ones, present a different structure on the surface from that which exists below. If, then, in the demonstration, these have not been separated, the focal point must be changed by means of the fine adjustment. In this way the capillaries in the web of the frog's foot may be seen to be covered with an epidermic layer, and the cuticle of certain minute fungi or infusoria to possess peculiar markings. Not unfrequently the fracture of such structures enables us, on examining the broken edge, to distinguish the difference in structure between the surface and the deeper layers of the tissue under examination.

7. *Contents.*—The contents of those structures, which consist of envelopes, as cells, or of various kinds of tubes, are very important. These may consist of included cells or nuclei, granules of different kinds, pigment matter, or crystals. Occasionally their contents present definite moving currents, as in the cells of some vegetables, or trembling rotatory molecular movements, as in the ordinary globules of saliva in the mouth.

8. *Effects of re-agents.*—These are most important in determining the structure and chemical composition of numerous tissues. Indeed, in the same manner that the anatomist with his knife separates the various layers of a texture he is examining, so the histologist, by the use of reagents, determines the exact nature and composition of the minute bodies that fall under his inspection. Thus, *water* generally causes cell formations to swell out from endosmosis; whilst syrup, gum water and concentrated saline solutions, cause them to collapse from exosmosis. *Acetic acid* possesses the valuable property of dissolving coagulated albumin, and, in consequence, renders the whole class of albuminous tissues more transparent. Thus, it operates on cell walls, causing them either to dissolve or become so thin as to display their contents more clearly. *Æther,*

on the other hand, and the alkalies, operate on the fatty compounds, causing their solution and disappearance. The *mineral acids* dissolve most of the mineral constituents that are met with, so that in this way we are enabled to tell, with tolerable certainty, at all events the group of chemical compounds to which any particular structure may be referred. Other reagents are occasionally useful, such as tannic and osmic acids, magenta, glycerine, solution of nitrate of silver, &c.

Mode of Conducting the Course.

I first commenced teaching practical histology in the year 1841, and have continued doing so uninterruptedly ever since. This long experience has satisfied me that the best method of teaching the subject is to place a microscope in the hands of each student who sits at a table opposite a good light. The tables should be arranged before an elevated chair, from which the teacher may watch the manipulations of every student. Two or more experienced assistants are always necessary.

Optical illusions.—The first lesson to be acquired is how to recognise the influence of transmitted light upon transparent solid, and hollow bodies, especially in their globular, flattened, filamentous, or tubular forms. Also the influence of direct and oblique light, the use of the diaphragm, modes of illumination, and the variations resulting from the use of low, medium, and high powers. It is from a neglect of this absolutely necessary practical knowledge that we are indebted to so many errors among microscopical observers, some describing as nuclei what are only the transparent centres of homogeneous bodies, and others confounding tubes with solid fibres.

Practical investigations.—The student having learnt the optical principles on which a microscope is constructed ; the use of its various parts ; how to observe ; how to measure the magnifying power of his instrument, and of various objects ; and the optical illusions so commonly presented to his eye, is now prepared to commence his histological inquiries.

The best object to examine first is the human coloured blood corpuscle, and it is of consequence that this should be done thoroughly, and all the physical facts regarding it, including the effects of reagents, carefully described by each student. It should be also accurately measured, as I adopt its size as a standard of comparison for other structures. This accomplished, all the elementary, molecular, cellular, fibrous, and tubular stuctures, are similarly examined *seriatim* in the order in which they are noticed in the first part of this work, each student making and describing his own demonstrations, and the errors he may fall into at once corrected by the professor or his assistants. Then all the special organs and products of nutrition, innervation, and reproduction, are also investigated in the order in which they are described in the second and third parts of this work. As the course proceeds, the student is instructed and practised in the method of demonstrating each tissue, how to make sections, how to inject, how to prepare, stain, and put up preparations, &c. The whole subject is further illustrated by the examination of selected specimens, from a histological collection containing upwards of 3000 preparations of the vegetable and animal structures, human and comparative, healthy and morbid. These are arranged so as to form a series of demonstrations in another room, which may be examined at leisure.

Preparation of the Tissues.

Thin sections of a tissue may be made in one of three ways: (*a.*) By an ordinary *razor*, or double-edged *scalpel*. (*b.*) By a *Valentine's knife* (Plate XXI. fig. 12). This knife consists of two thin, sharp blades, *a* and *b*. They are kept opposite each other by a sliding catch, *d*, and the distance between them can be carefully graduated by means of the fine screw *c*, which passes through the blade *a*, and acts by its point on *b*. The thin section is received between the blades, and is removed by separating them at the joint *e*, and agitating them in water. (*c.*) By means of an apparatus shewn in Plate XXI. fig. 11, A. B., termed *Stirling's section cutter*.* It consists of a wooden box, *d*, having on its surface a brass plate, A (upper surface shewn at B). The interior of the box is circular, and communicates with a short tube, *b*, at the bottom of which there is a fine screw, *c*. The tissue is placed in the tube, surrounded by carrot or orange peel. The tissue may now be elevated to any extent required by turning the screw; a razor or amputating knife is placed on the brass plate and pushed obliquely through the tissue projecting above its surface. The fineness of the screw enables us to make very thin and regular sections.

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* Journal of Anatomy and Physiology, May 1871.

It is often difficult to cut sections of certain tissues, owing to their brittleness or extreme softness. To accomplish this, the tissue may be surrounded by two bits of carrot, orange peel, elder pith, or spermaceti. The following paraffine mixture is useful for this purpose : Solid paraffine, 5 parts ; spermaceti, 2 parts ; axunge, 1 part. This mixture may be melted and poured into a mould, in the centre of which is imbedded the tissue under examination.

All tissues should, as far as possible, be examined in their natural condition, with no reagent except serum or aqueous humour. But it is frequently necessary to act on the tissues with chemical or physical reagents, so as to explore their structure. These reagents may be classified into (1.) physical reagents, such as heat, cold, and electricity ; (2.) chemical reagents, such as acetic acid ; (3.) hardening reagents, such as alcohol, chromic acid, &c. ; and (4.) softening reagents, such as nitric acid, maceration, &c.

1. *Physical reagents.* *a. Heat.*—It is evident that certain delicate tissues or fluids, such as nerve or blood, are best seen under conditions simulating as far as possible those in which they exist in the living body. Certain of these conditions, such as a degree of moisture and the temperature of the body, may be readily obtained by the use of an apparatus termed *Stricker's hot stage.* This consists of a strong flat brass box, accurately adapted to the stage of an Oberhauser or Hartnach microscope, having in the centre of it a small circular chamber, the bottom of the latter being made of glass, so as to permit reflected light to pass from the mirror beneath the stage. The box has inserted into each end a narrow brass tube for the ingress and egress of fluid, and attached to it there is a small centigrade thermometer which registers the temperature of the fluid in the box. Hot water is supplied to the box by means of an India rubber tube connecting it with a boiler, which, in turn, can easily be kept full by means of a tube leading from a cistern, or from one of the stop-cocks of the laboratory. It is evident that the temperature of the water in the box will be regulated by the rapidity of the flow, because if this be slow, the water has more time to cool by radiation, whereas if it be fast, a constant supply of hot water keeps the temperature high. The flow of water through the box is therefore regulated by means of an apparatus placed on the right hand side of the stage, consisting

of an upright of brass carrying a small conical glass tube, the apex of the cone being directed upwards, and drawn to a fine point. The base of the cone is connected with an india-rubber tube leading from the brass box, and the cone can be readily raised or depressed on the support, and fixed in any position by a screw. By means of this arrangement, the water is prevented from flowing rapidly through the box, and the flow can be regulated by raising or depressing the glass cone. This hot stage has been found useful in the examination of white blood corpuscles. A small drop of blood is placed on a covering glass, and a drop of tepid water having been previously introduced into the bottom of the circular chamber, the covering glass is placed over the chamber so as to form its roof, the drop of blood being on its under surface. Thus the blood corpuscles are seen free from pressure, in an atmosphere saturated with moisture, and at a temperature corresponding to the temperature of the body. The temperature may also be varied by regulating the flow of fluid through the box. The actions of various gases, such as carbonic acid or oxygen on the blood corpuscles, may also be observed by means of this apparatus. Two short brass tubes communicate with the circular chamber. One tube is for the entrance, and the other for the exit of the gas.

β. *Cold.*—A low temperature kills a living tissue, and soon hardens it. Tissues may be readily hardened by freezing. Those most suitable are lung, liver, spleen, kidney, and blood glands. The best freezing mixtures are the following: (1.) Ice. (2.) Ice, 2 parts; chloride of sodium, 1 part. (3.) Calcium chloride, 3 parts; snow, 2 parts. (4.) Potassium nitrate, 4 parts; hydrochlorate of ammonia, 100 parts; water, 200 parts.

γ. *Electricity.*—The action of either a continuous or interrupted current on a microscopical object, may be observed by the following arrangement: Two small triangular pieces of tin foil are cemented on the surface of an ordinary glass slide, of such a size that the bases correspond to the ends of the slide, and the apices approach within the 1-10th of an inch from each other. These serve as electrodes, and they may readily be brought into connection with a battery by means of wires kept in apposition to them by small, but strong, wooden clips. By this arrangement, the action of electrical currents and shocks on cilia, white blood corpuscles, or muscle, may be easily studied.

2. *Chemical reagents.*—α. The solution of *acetic acid* most serviceable, is prepared by mixing equal parts of ordinary acetic acid and distilled water. β. *Soda solution*, is caustic soda, 1 part; water, 25 parts. γ. *Glycerine* and *glacial acetic acid:* glycerine, 1 ounce; acid, 5 drops. δ. Price's pure glycerine. These all more or less dissolve and render transparent albuminous tissues. ε. *Tannic acid*, 2 grains to 1 oz. of distilled water, has a peculiar effect on the coloured blood corpuscle (p. 63).

3. *Hardening reagents.*—α. *Alcohol.*—The tissue should first be allowed to remain for several hours in dilute alcohol, and then be immersed in absolute alcohol. The retina may be hardened by changing the absolute alcohol every four hours for three days. β. *Chromic acid.*—For most tissues, a solution containing ·25 per cent. is suitable. For hardening nerve substance, a solution of chromic acid, 1 part; potassium bichromate, 2 parts; water, 1200 parts, for a week, and a fluid of twice the strength for six weeks are required (Lockhart Clarke). γ. *Müller's fluid.*—Potassium bichromate, 2½ parts: sodium sulphate, 1 part; distilled water, 100 parts, is useful for retina, &c., the tissue being allowed to steep for four weeks. δ. *Tetroxide of osmium*, OsO_4, in solution of from 1-10th to 2 per cent. has been found to harden retina, organs of Corti, epithelium, &c. In addition to these reagents, tissues may be hardened by drying (tendon), freezing (lung), or boiling (crystalline lens).

4. *Softening reagents.*—α. *Nitric acid.*—This acid dilute (1-4 water) readily softens muscle, causing it to split up into fibrillæ or discs. β. *Hydrochloric acid* (1-20 of water) is useful for extracting the earthy matter of bone. γ. *Nitric with chromic acid.*—Nitric, 2 parts; chromic, 1 part; water, 100 parts, also soften bone or tooth. δ. *Glycerine*, with the addition of a few drops of glacial acetic acid, macerates nerve and other tissues.

STAINING THE TISSUES.

The art of staining tissues has thrown much light on Histology by displaying structures which, without it, shew almost no trace of organisation. This depends on the affinity which certain parts of the tissues, and certain tissues, have for colouring matter. The following are the chief staining solutions:

1. *Magenta.*—This is used in the form of an alcoholic solution,

and is readily obtained by employing the fluid sold in small bottles by chemists, either dilute or not.

2. *Ammoniacal solution of carmine.*—Carmine, 10 grains; strong ammonia, 30 minims; glycerine, 2 ounces; distilled water, 2 ounces; rectified spirit, ½ ounce. Place the carmine in a test tube, add the ammonia, boil for a few seconds, let it stand for an hour, add the water, filter, and add the spirit and the glycerine. After steeping, remove the superfluous pigment by allowing the tissue to be immersed in an aqueous solution of glycerine, 2 parts of glycerine to 1 part of water. The pigment may be fixed by placing the tissue in acid glycerine (glycerine, 1 ounce; hydrochloric acid, 2 drops; glacial acetic acid, 5 drops).

Logwood.—Pulverise the ordinary extract, and add three times its bulk of alum. Mix well for twenty minutes in a mortar, first with a small, and then with a larger quantity of water. This, when filtered, should present a clear, dark violet colour. If it be a dirty red, add more alum. To one ounce of this fluid two drachms of 75 per cent. alcohol must be added. A few minutes will stain tissues with this solution even when previously hardened by alcohol or chromic acid.

3. *Nitrate of silver.*—A solution of ½ per cent. in distilled water is used for demonstrating the margins of epithelial cells in lymphatics, blood vessels, or on peritoneum. The tissue is steeped in it for two or three minutes, then in very dilute acetic acid (1 to 2 per cent.) for a minute or two longer, then placed in glycerine and exposed to the action of the light.

4. *Chloride of gold*, ½ per cent. solution, stains nerve tubes. The tissue is steeped in it for 20 minutes, and then washed in dilute acetic acid (1 to 2 per cent.).

In the manipulation of tissues by these various agents, it must be remembered that we frequently change their natural appearances. It would be as absurd to suppose that a nerve tube, with its solid central rod formed by coagulating fluids, exists in the living body, as it would be to suppose that a hard-boiled egg resembles the developing ovum.

INJECTION OF THE TISSUES.

The art of making successful injections can only be acquired by long practice, and by attention to many minute details, which must be taught during the performance of the operation. For this reason, only the compositions of a few of the principal injecting fluids will be given, and some general observations made. Injections may be either *opaque* or *transparent*, the former being employed when the tissue is thin and delicate; the latter, when the form of the tissue or inequalities on its surface are to be displayed. The fluid may be driven into the vessels either by a brass syringe made for the purpose, or still more slowly and equally by hydrostatic pressure. The former method is the one most generally adopted, and by it, with a skilful hand, good results may be obtained: the latter has been recently revived by an elaborate apparatus used by Ludwig, in which the hydrostatic pressure derived from the water-pipes of the laboratory may be measured by means of mercurial manometers. Injections should be made while the body is fresh, after the disappearance of *rigor mortis.* The chief points to be attended to are: 1. That the animal, or organ, and the injection, nozzles, and syringe, should be kept warm, at a temperature sufficient to guarantee a free and uniform flow of the fluid; and 2. that the pressure made should be moderate in amount, and slow and equable.

1. *Opaque injections.*—The liquid or menstruum is composed of melted wax or melted size. Ordinary sealing wax, diluted somewhat with turpentine, or, better still, with oil of rosemary, may be employed. If pure white wax be used, the greatest pains must be taken in grinding and mixing the colours. Size is prepared by melting 4 oz. of the best transparent glue in one pint of water, and then adding to it the colour, which must be kept constantly stirred. The advantage of wax injections is, that when cold, the vessels remain fully distended and round, while sections of the tissues may be kept hard. The finest preparations of this kind have been made by the injectors of the Vienna school, ever since the days of Lieberkühn; and the present eminent professor of that university, Hyrtl, continues to make the most beautiful injections in wax, after the method of his predecessors. Size injections, on the other hand, shrink when allowed to get dry, and hence they must always be kept moist in bottles, or, for microscopic purposes, mounted in closed cells with diluted spirit. The preparations made by Quekett and Hett in this manner have never been surpassed in beauty. The various colours employed are as follow:—

a. Vermillion.—This should be carefully ground down on a slab with oil or water, and all the coarser particles removed by lixiviation. To secure success, the ground paint should be examined microscopically, for if the particles are not much smaller than the blood corpuscles, they will not pass through the capillary vessels. 2 oz. of vermillion are to be added to 1 pint of the liquid or menstruum, and kept constantly stirred till used.

b. Chromate of lead.—This is obtained by dissolving 200 grains of acetate of lead and 105 grains of bichromate of potash in equal quantities of water, mix, pour off the supernatant fluid (acetate of potash), and mix the chromate of lead with 4 ounces of hot size. M. Doyère's method is to throw in saturated solutions of the two salts, one after the other, so that the formation of chromate of lead takes place in the vessels. It has been found, however, better to add gelatine in the proportion of 4 ounces in 8 ounces of water, to 8 ounces of the saturated solutions of each salt.

2. *Transparent injections.*—The fluid or menstruum employed here is a size made of transparent gelatine or of the compositions given below.

a. Beale's Prussian blue fluid, consists of the following parts: glycerine, 1 ounce; spirits of wine, 1 ounce; ferrocyanide of potassium, 12 grains; tincture of perchloride of iron, 1 drachm; hydrochloric acid, 5 drops; water, 4 ounces. Dissolve the ferrocyanide of potassium in 1 ounce of water, and the tincture of the perchloride of iron in another. Mix these gradually in a bottle, adding the iron to the ferrocyanide of potassium. Next the spirit, the glycerine, and the rest of the water, are to be mixed, and the colourless fluid thus obtained is to be well shaken up with the Prussian blue.

b. Turnbull's blue.—Ferricyanide of potassium, 10 grains; sulphate of iron, 5 grains; water, 1 ounce; Price's glycerine, 2 ounces; alcohol, 1 drachm. The iron is dissolved in the glycerine and water, and the ferricyanide of potassium and alcohol added.

c. Beale's carmine fluid.—Carmine, 5 grains; glycerine (with 8 or 10 drops of hydrochloric acid), ½ ounce; glycerine, 1 ounce; alcohol, 1 drachm; water, 6 drachms; ammonia, a few drops. Mix the carmine with a little water, and add 5 drops of *liquor ammoniæ.* To this add ½ oz. of glycerine, and shake. Add gradually the acid glycerine. Add the alcohol and water gradually, shaking the bottle thoroughly.

d. Carter's carmine fluid.—Pure carmine, 60 grains; liquor ammoniæ fortior, 120 grains; glacial acetic acid, 86 minims; solution of gelatin (1-6 of water), 2 ounces; water, 1½ ounces. Dissolve the carmine in the ammonia, and filter. Mix this with 1½ ounces of hot solution of gelatin. Mix the remaining ½ ounce of gelatin with the acetic acid, and drop it slowly into the solution of carmine.

e. Thiersch's yellow fluid.—Dissolve 10 parts of bichromate of potash in 110 parts of water, and make a solution of nitrate of lead of the same strength. Mix 1 part of the solution of bichromate of potash with 4 parts of a concentrated solution of gelatin, and 2 parts of the solution of nitrate of lead with 4 parts of gelatin. Mix these two gelatin solutions at a temperature of 75° to 90° F., and afterwards heat the mixture for half an hour to 212°. Then filter.

Preservation of the Tissues.

Many preservative solutions have been used, and different tissues require different fluids.

1. *Canada balsam.*—This substance has been more used than any other. It is best prepared by drying pure Canada balsam in a porcelain capsule in a hot-air chamber, until it becomes quite hard, and then dissolving the mass in chloroform or turpentine.

2. *Dammar fluid.*—Gum Dammar, ½ ounce; oil of turpentine, 1 ounce; dissolve and filter. This is then mixed with the following: gum mastic, ½ ounce; chloroform, 2 ounces; dissolve and filter.

3. *Potassium acetate.*—A saturated solution of this salt is the best medium for preserving all tissues which have been acted on by osmic acid.

4. *Glycerine.*—This substance, either natural or containing 1 or 2 drops of hydrochloric acid to the ounce, is suitable for preserving tissues not made too transparent by it.

5. *Glycerine jelly.*—Allow a certain quantity of gelatin to soak for 10 hours in cold water, when it will be found swollen and soft. Melt in warm water. Add an equal amount of strong glycerine. This is suitable for cartilage, blood vessels, kidney, &c.

6. *Weak spirit* (1 part spirit, 3 parts of distilled water) is well suited for muscle, blood vessels, &c.

7. *Naphtha and creosote.*—Creosote, 3 drachms; wood naphtha, 6 ounces; distilled water, 64 ounces; chalk, a sufficient quantity.

Mix the naphtha and creosote together, and add as much chalk as will make a paste. Add water and mix thoroughly. Add a few bits of camphor, the size of a hazel-nut, and allow the whole to stand for two or three weeks. Pour off the supernatant fluid for use.

These are the principal fluids in which microscopical preparations may be preserved. Cells for mounting and preserving microscopic preparations may be made with Brunswick black, Canada balsam, Dammar varnish, or glass. Those made of Brunswick black are objectionable, because in course of time the material runs into the cell, and the preparation is spoiled. Canada balsam sometimes cracks in old preparations, and allows the preservative fluid to escape ; at other times, it softens, and the covering glass is easily displaced. On the whole, cells made of thin glass are the best for all purposes.

These, and numerous other practical details, it is useless to describe in words, as they can only be learned in the laboratory.

PRACTICAL EXPERIMENTAL PHYSIOLOGY.

This department of Physiology includes a description of the methods of research followed and the instruments employed in the investigation of physiological phenomena. Of late years it has advanced with great rapidity, and has been fruitful in many important discoveries. When taught practically, the student should, as far as possible, assist personally in the experiments, acquire a knowledge of the apparatus employed, and learn how to observe and record results.

EXPERIMENTS ON THE MUSCULAR SYSTEM.

As we have seen (pp. 80, 82), living muscle possesses two properties—contractility and electro-motive power. The investigation of these functions requires the use of electrical and other apparatus, which we shall now describe. To understand them, it is necessary that the student should, in the first instance, become acquainted with the general phenomena of magnetism and electricity, as already explained at pp. 144 and 146.

Apparatus.

1. *Batteries.*—These have already been described at p. 152. Daniel's battery is useful where we wish to have a current con-

stant in quantity. Bunsen's is too powerful for most physiological experiments. Grove's battery is powerful and constant. It is desirable to have eight or ten small elements of this description for experiments in which we wish to graduate the strength of the current. Smee's battery is much used, because it requires only one fluid, and is easily manipulated, but it has the disadvantage of being inconstant; so that in comparative experiments it ought not to be employed. It is important in using any of these batteries to remember that the zinc requires frequently to be amalgamated, a process easily performed by rubbing over the zinc with a little flannel or cotton wool dipped in mercury and dilute sulphuric acid. If this be not done, the zinc, which is usually contaminated with other metals, will not be homogeneous, and numerous small galvanic circles will be formed between these impurities and the particles of zinc, leading to rapid wasting of the latter. Where very careful amalgamation is required, the following fluid is useful : *Berjot's amalgamating liquid.*—Dissolve at a gentle heat, 200 grammes of mercury in 1000 grammes of a mixture of 1 part by weight of nitric acid and 3 parts of hydrochloric acid, and then add 1000 grammes of the latter.

2. *Du Bois-Reymond's electromotor or induction apparatus.*—The production of electricity by induction has been described at p. 155. A side view of the instrument is seen in Pl. XIX. fig. 1, and an end view in Fig. 2. It consists of a primary coil, R_1, of thick copper wire, insulated with silk, and of a secondary coil, R_2, consisting of numerous coils of fine copper wire, also well insulated. The centre of the primary coil, R_1, contains a bundle of thin iron wires, which are rendered magnetic during the passage of the electrical current round the primary coil, and thus increase the amount and intensity of the induced current obtained from the secondary coil (Fig. 2 S). The primary coil is firmly fixed ; but the secondary one slides in a double groove in the board B B, and this board has a hinge which allows one-half to lie under the other, as depicted in Fig. 1. When, however, we wish to increase to a greater extent the distance between the primary and secondary coils, we unloose a hook, seen on the board under R_1, and fold out the board to double the original length. A scale, divided into centimetres and millimetres, is pasted on one side of the upper surface of the board, and we can thus, in comparative experiments, carefully graduate the distance between the two coils. The nearer the coils

are to each other the more intense the shock, and *vice versa.* The shock of induced electricity can, however, only be obtained at the moment of opening and at the moment of closing the primary current. This regular opening and closing of the primary circuit is effected by an apparatus placed at the end of the instrument, termed *Wagner and Neef's hammer.* This apparatus will be understood by referring to Plate XIX. fig. 2. Here we have K representing the battery from which voltaic electricity is derived. It passes from the positive pole in the direction of the small arrow to the brass pillar *a.* Having run up this pillar, it goes along a steel spring seen over S, and as the elasticity of the spring keeps a small square bit of platinum on its upper surface in apposition to the platinum point of the screw S_1 the current passes into S_1 from thence by a copper wire to S_{11}, and from thence, as indicated by the small arrow ⟶, round the wire of the primary coil, R_1. It now goes from R_1, as indicated by the lower small arrow, to a small U-shaped piece of soft iron surrounded by the wire, and thus converts it into an electro-magnet, which draws down the armature of soft iron (the hammer) on the free end of the spring, and thus the contact between the back of the latter and the screw point S_1 is broken. When this happens, the primary current is broken at S_1, the electro-magnet loses its magnetism, releases the spring, which flies up by its elasticity, and again establishes the current. Thus by the alternate breaking and forming of the primary current, a secondary current is induced in R_2, which has no connection by wire with R_1. It is the secondary current (Faradic electricity) which is used in many physiological experiments.

Helmholtz's modification of the apparatus.—When a muscle or nerve is irritated by an induced current from the secondary coil, R_2, it receives a rapid series of shocks, because the hammer acts with great rapidity. If the hammer acted slowly, so that we could distinguish between the effect of the opening shock and the closing shock, it would be found that the effect is much greater in the case of the former. The reason of this is that the opening shock is more rapid in its course, its velocity rising rapidly from zero to a maximum. If then we can retard the opening shock, we may render it equal to the closing one. This Helmholtz has accomplished by an arrangement in which he makes the hammer, when attracted by the electro-magnet, not open the primary circuit, as in the apparatus just described, but close an accessory circuit so as to weaken the primary one. The accessory circuit (Pl. XIX. fig. 2) is β running from a to S_{III}. Beneath the centre of the steel spring is a middle pillar, having in its base the binding screw x to which a wire in connection with the negative pole of the battery is attached. The accessory circuit, $a\ \beta\ S_{III}\ S_{II}\ R_1$, continued in the direction of the lower arrow down an electro-magnetic pillar to another arrow which leads to x, S, and a, is closed when the steel spring is in contact with S. When this is the case, the primary circuit is so weakened that the electro-magnet loses its magnetism, and the spring flies up, the primary circuit being now formed and the accessory broken. By this arrangement the velocities of the two shocks are equal, and the apparatus is better adapted for careful physiological research.

3. *Du Bois-Reymond's key* (Plate XX. fig. 4).—When we wish to open or close a circuit, we may do so either by detaching or fixing the wires by binding screws, or by using small cups filled with clean mercury, into which the ends of the wires dip. This latter expedient is adopted in very delicate stimulation experiments. It is, however, preferable in most experiments to use the galvanic key. It consists of a plate of vulcanite firmly attached to a strong rectangular vice-pin. On the plate there are two small thick pieces of brass, each bearing two binding screws, *b*, *c*, placed at a short distance from each other. These can be united by raising or depressing the brass arm, *d*, which has an ivory handle, and turns on a pivot attached to the piece of brass, *c*. The wires from the battery are connected with the two internal binding screws, while the two external ones connect those going to the nerve or muscle. When the handle is pushed back, the key is opened, and the current passes to the tissue to be irritated ; but when the handle is pushed forwards and the key closed, as seen in the figure, the current passes along the thick arm of brass, back again to the battery.

4. *Pohl's commutator, gyrotrope, or rheotrope* (Plate XX. fig. 6).—This instrument is for the purpose of inverting or changing the direction of a current of electricity. It consists of a round disc of wood or vulcanite having six small mercury cups, A, B, a, b, α, β, in it substance, in connection with each of which there is a binding screw. The cups a, b, are in con-

stant connection with a pair of brass wires, P, O, brought close to each other at S by a piece of glass tubing, into which they are inserted. These brass wires carry two brass arcs transversely, *m*, *n*, *o*, and *p*, *q*, *r*, having their ends free, so that by moving the glass bridge S forwards or backwards, the ends may dip into the cups α, β, or A, B. The apparatus may be used with or without the cross wires *h*, *i*, the wire *h* being curved in the middle so as not to touch *i*. (1.) *Without the cross wires.*—The wires from the battery or key are fixed into *a* and *b*. The current cannot pass across the bridge S, because the centre is composed of glass. If now two wires are in connection with α, β, and the arcs dip into these cups, as shewn in the figure, the current will flow along those wires. If, on the other hand, two other wires are in connection with the cups A, B, and the ends of the arcs are dipped into them, then the current will pass from A to B. Thus, by simply *turning* the central bridge bearing the arcs, we can send a current either in the direction of α, β, or A, B, at pleasure. (2.) *With the cross wires.*—Suppose, now, the wires *h*, *i*, are inserted so that the wire *i* connects the cups α, B, and the wire *h*, β and A, a different use is made of the instrument. If the current, for example, entered at + *a*, it would follow the direction *a*, P, *r*, α, β, *n*, *o*, and back to the battery by—*b*. If now we reverse the bridge, the direction will be *a*, P, *q*, A, along the cross bar *h* to β, α, from thence along the cross bar *i* to *m*, *o* and — *b*, and from thence back to the battery. By this last arrangement, the current has passed along the circuit between α and β in such directions that it can be sent up or down a nerve at the will of the experimenter. The course of the current, however, in these cases, can only be clearly understood by a study of the instrument itself.

5. *Muscle telegraph* (Plate XIX. fig 7).—This is an apparatus very useful in experiments on both muscle and nerve, and it consists of the following parts: A brass forceps, A, at the end of an arm capable of sliding up and down on an upright round pillar of brass. This is for holding the femur of a frog's leg which has the gastrocnemius muscle attached to it. The screw S, permits the forceps A, to be rotated in any direction, and fixed securely in any position. Into the tendon of the gastrocnemius a small hook *h* is inserted, to which is attached a fine thread passing round a pulley *p*, and then downwards along *a* to a little balancing bucket *b*, containing a few shot. On the

same pulley we have a long arm, bearing at its free end a round coloured disc of mica, which moves in front of a piece of white plate in the direction of the arrow. By the contraction of the muscle, the signal is pulled up to a greater or less extent, and thus the effect of irritation on it may be seen by many observers at once. If the muscle is to be stimulated by the direct application of a current, the wire from the positive pole is *a* attached by the bending screw S, and that in connection with the negative, *x*, is wound tightly round the hook fixed in the *tendo Achillis.* The upright bearing the pulley and disc, is fixed in a wooden socket which can move in either direction in a groove, and is retained in its position by a strong screw, Z.

6. *Du Bois-Reymond's polarizable electrodes* (Pl. XIX. fig. 6). —This apparatus is designed for the purpose of stimulating a nerve in any situation. It consists of *a*, a strong wooden stand bearing a round piece of vulcanite *b*, in which we have two small binding screws. In connection with this we have a long arm, having in its centre a universal joint which can be tightened in any position by the screw *c*. This bears the essential part of the apparatus, which consists of two triangular platinum points or plates, *e*, each soldered to a thick wire passing through a square block of ivory. This block has two small screws on its upper surface, which are for the purpose of adjusting the distance of the platinum points from each other. Underneath the ivory block and electrodes we have a glass plate for insulating the wires. When the instrument is used, the nerve is laid across the two electrodes, and the portion of nerve on and between them is thus stimulated.

Experiments on Contractility.

The property of contractility can be readily demonstrated by shewing that a piece of living muscle, or a whole muscle, contracts when irritated. The irritation may be mechanical, such as by a blow, or a pinch; chemical, as by the action of a solution of common salt; electrical, on applying electricity; or vital, on stimulating a nerve. The truth of the Hallerian doctrine of contractility, namely, that it is inherent in muscular tissue, and not dependent on nerve may be demonstrated by two experiments.

1. *John Reid's experiment.*—Remove the sciatic nerve from the leg of a living frog, and irritate the muscles by an induced cur-

rent of electricity. At first there is violent spasm or tetanus, but after some time the muscles cease to respond to the stimulus. Thus the contractility has been exhausted. But allow the frog to live for six, eight, or twelve hours, and it will be found, on again applying the stimulus, that the contractility has returned, while sensibility has not.

2. *Bernard's Woorara experiment, as shewn by Du Bois-Reymond.*[*]—This requires the following apparatus: 2 muscle telegraphs, 1 of Du Bois-Reymond's polarisable electrodes, a Pohl's commutator, without the transverse bars, a key, an induction apparatus, and a Smee's or Daniel's element.

Mode of preparing the frog.—The frog is chosen for many of these experiments because it is easily manipulated, and the muscles and nerves can be quickly isolated. First, decapitate the animal, or cut through the *medulla* with a sharp pair of scissors, to destroy sensation, then holding it in the left hand by the legs or lower part of the body, turn the animal round, and cut the body through about the middle of the abdomen. Then sieze hold of the back bone with the fingers and thumb of the left hand, and with the forefinger and thumb of the right hand, quickly drag off the skin of the legs. Then various preparations may be made according to the nature of the experiment. The limbs may be used without further dissection, or the sciatic nerve may be dissected out (Plate XIX. fig. 3 *b*), or the gastrocnemius muscle, with or without the sciatic nerve, may be isolated. In the experiment about to be described the sciatic nerve is first dissected out. This is easily done by pressing the muscles of the thigh forwards with the thumb and forefinger of the left hand, when the nerve usually starts into view. Then with a pair of blunt-pointed scissors, separate the nerve from the surrounding tissues, taking great care not to injure or even touch it. Cut through a small branch which runs downwards and inwards a little above the middle of the thigh. Trace the nerve as high up as possible, so as to have it of considerable length, cut it, and with a blunt quill or an ivory point turn it down upon the gastrocnemius in order to keep it moist. Then remove the muscles of the thigh, except the attachment of the gastrocnemius, and snip through the femur just below its head. Now cut through the *tendo Achillis*, and pull the gastrocnemius upwards to the knee. Then amputate the leg below the knee, and you have a preparation consisting of a femur having the gastrocnemius attached to its lower end, together with the uninjured sciatic nerve. A hole in the gastrocnemius tendon should now be made for the steel hook of the muscle telegraph.

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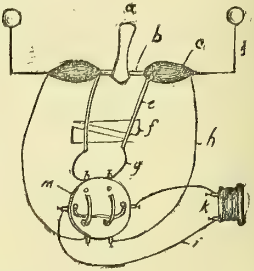
[*] Leçons sur les effets des substances toriques, 1857, p. 277.

Woorara solution.—Dissolve 5 grains of woorara in a little weak spirit, rubbing it up in a small mortar, and then add 5 drops of glycerine and three drachms of distilled water. Each minim contains about the 1-38th part of a grain, and usually 6 minims, or about the 1-6th part of a grain is a sufficient dose for the experiment.



The experiment consists in first putting a ligature on the femoral artery in one of the limbs of a frog, or tying a tight cord round the upper part of the limb, so as to prevent the poison entering it; then with a syringe having a fine nozzle we inject, under the skin of the back, six minims of the above solution, and allow the animal to come thoroughly under its influence. It should take about half-an-hour to completely prostrate the animal, so that it rests on its belly unable to move. Care must also be taken not to inject too strong a dose of the woorara. Two dissections are now made in the manner already described. In the one the sciatic nerve has been poisoned by woorara, and in the other, it is quite healthy. Each limb so prepared is now attached to a muscle telegraph (see Fig. *d*), a pair of brass forceps being placed midway between the two telegraphs, so as to hold the two femurs (*a*), and the two nerves (*e*) are laid across the platinum points of Du Bois-Reymond's electrodes (*f*). These electrodes are connected by wires (*g*) with two of the cups of Pohl's commutator by binding screws, and from the other two cups, wires (*h*) proceed to, and are wound round, the hook fixed into the *tendo Achillis* of each muscle (*c*). The two cups of the commutator, into which the wires bearing the arcs are permanently fixed are connected with two outer binding screws of a key placed at *i*. From the two inner binding screws, wires (*i*) proceed to the secondary coil of an induction apparatus (*k*), while the primary coil is placed in the circuit of a Daniel's or Smee's battery, consisting of one cell. By this arrangement of apparatus, the commutator enables us to reverse the electric current so as to irritate the two nerves or the two muscles at pleasure. If successful, the result will be that when both nerves are irritated, only one muscle contracts and elevates the disc of a telegraph, namely, the one supplied by the nerve not poisoned by woorara; whereas, if the current be sent through the *muscles*, both contract, and the two discs are elevated. Thus, although the nerve has been poisoned by woorara, the contractility of the muscle remains, a fact which demonstrates the truth of the Hallerian doctrine that it is a property inherent in muscle, capable of being excited by any direct stimulus, and not dependent on the nervous system.

Kölliker's experiment.—A reverse experiment to the one just described is made by destroying the contractility without affecting the motor nerves by means of *veratria*. The experiment is conducted in the same manner, and it will be found that when both *nerves* or both *muscles* are irritated, one muscle contracts, namely, the one which has not been poisoned.

Experiments on the evolution of electricity by muscles.

All muscles evolve a constant stream of electricity (p. 82), passing from any natural or artificial longitudinal section to any transverse section (p. 166). In order to demonstrate this important fact, the following apparatus is necessary :

(1.) *A multiplying galvanometer* (see p. 149).—This instrument is represented in Plate XIX. fig 4. It consists of an astatic combination of two magnetic needles (p. 149), the lower of which is surrounded by a coil of fine copper wire. When even a feeble current of electricity is passed through this wire, a deflection of the needle is obtained. The instrument must be carefully arranged, the needles rendered perfectly astatic so as to point from east to west, and the whole levelled by means of three screws supporting a brass disc (*a*) : on the surface and in the centre of the disc is a brass box (*b*), on the top of which is fastened a boxwood frame (C) supporting the coils of wire. This brass box can be made to revolve by means of a screw (*g*), which acts as a fine adjustment, and enables us to place the coils of wire in any direction we please. The disc (a) is usually graduated into 1-10ths of a degree. The two pillars (hh) support a horizontal bar, having suspended from its centre, by a single fibre of spun silk, the astatic combination of needles, which are usually kept steady from vibrations by a small magnet placed on a line with the direction of the coils of wire. On the top of the wooden frame (C) we have a circular scale of white paper divided into parts of 90°, which is so arranged that zero is also parallel with the direction of the coils of wire. The instrument is protected from dust and currents of air by means of a cylindrical glass cover. It must be securely fixed, carefully levelled, and made free from vibration.

(2.) *A pair of Du Bois-Reymond's non-polarizable electrodes.* (See Plate XIX. fig. 5.)—They consist of shallow troughs of zinc, carefully amalgamated on the inner surface. In connection with each trough there is a brass pillar (c) supporting two binding screws. The trough is placed upon a piece of vulcanite which acts as an insulator. Into each trough we place a saturated solution of sulphate of zinc. We must now prepare two cushions of Swedish filter-paper as follows: Fold a sheet so as to make a bundle or cushion about half an inch thick. Place it in the trough so that one surface rests everywhere in close contact with its bottom, bend one side over, as shewn in Fig. 5, b, and with a sharp razor cut the cushion so as to make a perpendicular surface. The cushions being thoroughly saturated with the sulphate of zinc solution would exercise an irritant action on the muscle, if laid upon them, and would cause it to contract. This is avoided by making two thin films or plates of sculptor's clay moistened with saliva. One is placed on the surface and perpendicular section of each cushion, as seen in Plate XIX. fig. 5 (g). Strips of bladder well soaked in white of egg may also be used for this purpose.

(3.) *Arrangement of apparatus.*—The two troughs, prepared as already described, are placed opposite to each other, at a distance of about a quarter of an inch. A thin wire is conveyed from each trough to the two innermost binding screws of a key. From the two outer binding screws, wires pass either directly to the galvanometer or to a special apparatus termed the *commutator*. This is a mahogany box, having inside a coil of wire to increase the resistance to the electrical current, and a series of brass plates and movable contact levers connected with each other, so that the muscular current passing through it can be diminished or inverted at will.

In order to prove that the apparatus does not itself produce any electric current, the two troughs should be connected with each other by a little oblong pad of blotting paper wet with the solution of zinc sulphate. The key is now opened, and if the apparatus be in order, the needle is unaffected. Any long muscle of a frog can be dissected out, the gastrocnemius is best, and a clean transverse section made with a pair of sharp scissors. The piece of muscle thus prepared, is now laid upon the plates of moist clay on the cushions in the troughs, so that its transverse section is placed accurately against the one cushion, and its longitudinal section against the other. The key is now opened, and a deflection of the galvanometer needle at once indicates the presence of a current of electricity, and the direction in which one pole of the needle is deflected shews the direction of the current. The key is now closed, and when the needle, after oscillating, stops at zero, the position of the piece of muscle should be reversed, and the key opened, when it will then be found that the needle will be deflected in the opposite direction to that of the first experiment. The experiment may be modified by placing a *transverse* section, or a longitudinal section, against each cushion, when there will be no or little effect on the needle. For this purpose, and for ascertaining the various electrical conditions of points of the surface of the muscle, there are many subsidiary contrivances, termed *supporting plates*, *rheophoric tubes*, &c., a knowledge of the use of which is best acquired by practice.

It having thus been clearly shewn that a piece of living muscle evolves a current of electricity, it may next be demonstrated that when the muscle is thrown into a state of contraction, this property is diminished. For that purpose it is necessary that the muscle have attached to it the uninjured sciatic nerve. It should then be adjusted on the two cushions, as previously described, while the nerve is laid gently on the platinum electrodes, which are in connection with an active induction coil, a key intervening. Deflection of the needle by the muscular current is now allowed to take place, and then to come to rest. On opening the key between the battery and the platinum electrodes, the muscle on the cushions is at once thrown into a state of contraction through the irritation of the nerve, and the needle of the galvanometer will be seen returning towards zero. Thus it is proved that the intensity of the electro-motive power is opposed to that of active contractility. (See p. 168.)

Numerous other structures, both animal and vegetable, such as skin, intestine, stems, leaves, bark, &c., may be examined with the view of ascertaining the presence or absence of a current of electricity.

Du Bois-Reymond's experiment to shew the presence of a muscular current in the living human body.—This will be understood by referring to Plate XIX. fig. 10, where an individual is represented grasping a roller, *c*, attached to two wooden supports firmly screwed to the table, so that the forefinger of each hand is immersed in, and touches the bottom of, the trough *b*. If the muscles of both arms are relaxed, there is no effect on the needle of the galvanometer *a*, but if the muscles of one of the arms are contracted by firmly grasping the roller, in many individuals we see a feeble deflection of the needle. Among the numerous students attending the practical physiology class during each session, a very few are found capable of causing this deflection, and we have observed that a large proportion of the successful individuals are of what is usually described as the sanguine temperament, having often red hair.

Experiments on the effects of muscular irritation.

This investigation, which is of great importance therapeutically, should be conducted in the following manner :

(1.) *Effect of a continuous current* (p. 82).—The hind leg of a frog is held by a pair of strong brass forceps, sliding on a round pillar of brass which is fixed into a solid wooden stand. Such a pair of forceps may be seen on the left side of fig. 7, Plate XIX. A. The limb so fixed is to hang down loosely, the knee being flexed. Two wires from a Daniel's or Smee's element are attached to the inner binding screws of a key. Wires are also conducted from the two outer binding screws, one being fixed by the screw S (Plate XIX. fig. 7), while the other is attached to the frog's foot. It will now be found that the muscles of the limb contract on opening and on closing the key, but there is no contraction while the key is open, that is during the passage of the continuous current. A continuous current, however, effects electrolytic changes in the muscle.

(2.) *Effect of an interrupted current.*—By the same arrangement of apparatus, it may be shewn that an interrupted current stimulates the muscle on the opening and closing of the key, and if this be done so rapidly that the muscles have not time to become relaxed before they receive a fresh shock, a constant state of rigidity or *tetanus* is occasioned.

(3.) *Effect of an induced or Faradic current.*—When an induction apparatus is employed for stimulating the muscle, the latter at once becomes tetanic, even although the same galvanic element is used to produce the induced current, as was employed in the two previous experiments. This shews that an induced current irritates much more strongly than either a continuous or an interrupted current.

Production of tetanus. — Tetanus is a state of permanent muscular contraction. It may be studied by the following illustrative experiments :

(1.) *By mechanical violence.*—Kill a frog by violently striking its head against the table. It will usually be found that for some minutes after death, the body becomes rigid from the tetanic condition of the muscles.

(2.) *By an induced current.*—As has been above described, tetanus is produced by an induced or *Faradic* current.

(3.) *By saline solutions.*—Prepare the limb of a frog in the usual way, and expose the sciatic nerve. Place the limb on a glass plate, and allow a drop of a strong saline solution to fall upon the nerve. In a few minutes the muscles become tetanic from the irritant action of the saline solution on the nerve.

(4.) By *Kuhne's apparatus*, consisting of a pair of vertical forceps fixed over a circular glass plate, the irritant action of many different acid, alkaline, and saline substances can be examined. The muscle preparation is fixed in the forceps, so that either it or the nerve are suspended over the glass plate. The latter may be elevated or depressed by a screw placed underneath it, so that the irritant solution, the effect of which is to be examined, may be brought into contact with the extremity of the muscle or nerve.

(5.) *By Heidenhain's Tetanometer.*—Another very ingenious mode of producing tetanus is effected by the use of an apparatus termed *Heidenhain's hammer* or *tetanometer.* The use of this instrument is to beat the nerve supplying a muscle or limb with great rapidity, and thus, by frequent mechanical irritations, produce tetanus. It is shewn in Plate XIX. fig. 9, and consists essentially of a modification of Neef's hammer, already described in connection with the induction coil (p. 527). The apparatus rests upon a vulcanite plate, K, supporting a brass column, a, which carries the lever L, in the middle of which is the armature of the electro-magnet (near L). This lever turns upon an axis at a, and may be relaxed or tightened by turning the screw S, which acts upon a spiral wire above it, marked with a smaller s. The pillar C supports, on a horizontal arm, the screw $S_{,}$, the point of which rests on a small piece of platinum on the upper surface of the lever. It is at this point the current is broken, and thus the hammer caused to vibrate. In the base of C we have a screw, $S_{,,,}$, which secures the wire coming from the positive pole of a galvanic element, while the screw Z receives the wire in connection with the negative pole. When used in the present experiment, the screw $S_{,,}$ is attached, by a piece of copper wire, with the screw $S_{,,,}$. The hammer, properly so called, is seen at *h*. It is made of ivory, and beneath it there is an ivory support, *t*, which receives the nerve in the groove h^1. Behind the ivory support there is a small ivory axle, A, fixed between two brass notches, and caused to move slowly by the pressure of the spring '*p*. By means of the screw S'''', the whole of this part of the apparatus may be elevated or depressed at pleasure. When the sciatic nerve of a limb (which is placed on a glass-support, or held by a pair of forceps before the apparatus) is placed in the ivory groove, and rapidly beaten by the ivory hammer, which is worked by the electro-magnet, the muscle becomes at once tetanic. The nerve is usually rapidly beaten through, and then it is necessary, in order to repeat the experiment, to attach its end by a fine silk thread to the ivory axle, and by turning the latter, to drag through a fresh piece of nerve. The only difficulty in using this apparatus is, that the different parts must be so adjusted with reference to each other that the nerve be beaten with a proper amount of force and rapidity.

(6.) *By Poggendorff's wheel.*—Another mode of producing tetanus by an interrupted current is by means of an instrument termed *Poggendorff's wheel.* This instrument consists of a wooden disc or wheel having twenty or more spaces cut out of its circumference, which are occupied by pieces of brass, alternating with pieces of ivory. The pieces of brass are connected alternately with each half of the axle, the two halves being insulated from each other in the centre of the wheel by an intervening piece of vulcanite or glass. Two stiff brass springs, having screws at their bases, are caused to press firmly against the margin of the wheel, so that while the wheel is being rotated, the flattened ends of the springs touch alternately the pieces of ivory and the pieces of brass. The binding screws in connection with the springs receive wires coming from a galvanic element, while there are two others on the supports of the axle from which wires may be conducted to a muscle. When the connections have been thus made, and the wheel rotated slowly, the muscle contracts and relaxes alternately, but when turned quickly, it becomes tetanic.

(7.) *Ritter's tetanus.*—It may also be demonstrated that if a continuous current of electricity be allowed to traverse a nerve attached to a limb in the upward direction, that is centripetally, for two hours (the nerve being kept moist and warm), and the current be then suddenly interrupted by moving the electrode *next* the free end of the nerve, the muscles become suddenly tetanic. This has been termed the *tetanus of Ritter.*

(8.) *By strychnine.*—Tetanus may also be produced by poisoning a frog with a solution of strychnine. This poison, injected hypodermically, increases the reflex action of the spinal cord, so that the slightest irritation at once throws the animal into a state of tetanus.

Effects of the opening and closing induction shock on a muscle. (See p. 82.)—This may be studied accurately with the aid of an instrument termed *Pflüger's falling apparatus* or *trip-hammer.* A view of this instrument is seen in Plate XIX. fig. 8. On a plate of vulcanite, E, there is a brass plate, having two uprights, *d d*, between which we have the steel axle of the hammer *e*. This hammer consists of a long rectangular handle, *a'*, and of a large steel head, *i*. On the left side of the latter we have a small steel rod, *m*, pointing downwards, and tipped with platinum. Above the hammer head, there is an electro-magnet, A, placed between the two supports *d d*, which may be fixed at any height by the screws *n n*. When this electro-magnet is called into action by a Smee's element, the head of the hammer is supported as seen in the figure. If, however, the galvanic circuit be opened, the hammer head falls and strikes against the end of the lever P at *q*, forcing it downwards, and thus breaking the contact of the other end of the lever with the screw-point *r*. At the same moment, the platinum point *m* falls into the conical steel trough X, which contains mercury. By this arrangement the instrument may be introduced into two galvanic circuits, and the moment the hammer head falls, the one circuit is closed and the other opened. The connections are made, for the first circuit, by wires attached by the screws *c* and *y*, and for the other by wires attached to the screws *t* and *u*. Suppose the hammer head to be in the position represented in the figure, and a muscle preparation interpolated into each circuit. Allow the hammer head to fall, and the point *m* to dip into the mercury in X, and the muscle in the circuit II, passing in the direction *c, d, h, i, m, x, y*, will receive the *closing* shock, while that in the circuit, marked I, *t*, P, *r*, *u*, will receive the *opening* one, because the circuit is broken by the forcible separation of the lever P from the screw *r*. Thus the action of the two shocks may be compared. At Z, underneath the handle of the hammer there is a spring catch which receives it when the hammer falls, holds it securely, and thus prevents vibration.

M'Kendrick's apparatus for measuring tetanus.—This enables us to calculate with readiness the number of distinct galvanic shocks necessary to produce tetanus. It consists of a series of wheels so arranged that if one of them make a revolution in a minute, the next will perform twelve revolutions in the same space of time, the third, 144 revolutions, and so on. Each of these wheels carries on a prolonged axle one or more small wheels of brass, having portions of the circumference cut out at equal distances, and small pieces of ivory interpolated. A steel spring is caused to press against the circumference of one of the wheels while it revolves, and an electric current passing through the instrument is opened each time the spring passes from the brass to the ivory, and closed when it passes from the ivory to the brass. The time occupied by the revolution of the first wheel is calculated by causing it to operate on a spring in connection with a small bell, so that the bell rings at the end of a revolution. Knowing the time occupied by the first wheel, we also know the second revolves twelve times as fast, and the third 144 times, and so on. By means of this arrangement, electric shocks can be transmitted to a muscle or nerve, varying in rapidity from 12 to 3000 a minute. The interval between the shocks may also be calculated to the 1000th of a minute.

Experiments on muscular fatigue.—The only satisfactory way of studying the gradual fatigue of muscle, when stimulated to do a certain amount of work, is to obtain a tracing on a cylinder, or plate of glass, by means of an instrument called a *myographion*, or muscle-writer (*μυων*, a muscle; *γραφω*, I write). Various myographions have been constructed for this purpose, but the most convenient is that of Pflüger, shewn on Plate XX. fig. 5. It consists of a solid wooden stand, S, into which is fixed a strong brass upright, F, carrying upon it a moveable forceps, Z. Into the forceps the end of a frog's femur is securely fixed, the gastrocnemius muscle being attached to it, and hanging downwards. Into the *tendo Achillis* a small hook is inserted, which supports by its other end the lever apparatus *d b*. This lever is a double framework, which moves freely on an axle at the top of the support *a*. At one end of the lever there is an apparatus bearing a stylette, which is employed for making tracings on a plate of smoked glass, P, moving in a frame, B, or still better, a tracing may be obtained on a revolving cylinder. Underneath the lever there is a balance, g, attached by a small hook, *f*, to a swivel apparatus, *c*. Into this balance a weight is placed sufficient to overcome the contraction of the muscle, and the consequent elevation of the lever, when the stimulation is removed. In order to keep the muscle and nerve alive for a considerable time, a square glass case may be placed over it, as shewn in the figure, containing moist blotting paper. By means of this apparatus many interesting experiments may be made, such as the tracing of a muscle stimulated by the opening and closing of a continuous current, the effect of the opening and closing of an induced current, and the effect of muscular fatigue from long-continued stimulation applied directly to the muscle or to the nerve supplying it.

EXPERIMENTS ON NERVE.

The nerve current is demonstrated in exactly the same manner as the muscular current (p. 535). To increase its amount, the nerve should be doubled, and both transverse sections placed in apposition to the cushion (pp. 97 and 169).

Effects of electricity on a nerve.—It is easily demonstrated that if a current of electricity pass through a motor nerve, it irritates it, and causes contraction of the muscle or muscles supplied by it. It must not be supposed that the electricity is conveyed along the nerve to the muscle ; it only stimulates the former, and calls into action the nerve force which causes the latter to contract. It has been found, however, that the presence and amount of the contraction depends partly on the strength and partly on the direction of the current. This has already been explained theoretically (pp. 169, 176).

Experiments on Pflüger's law of contraction.

To graduate the strength of the stimulation-current, we require ten or twelve small Grove's cells, the zinc surface of each being about 2½ square inches ; and also a special instrument termed a *rheocord.*

The rheocord.—A view of this instrument is seen in Plate XIX. fig. 11. It is for the purpose of enabling us to send a current of definite strength through a nerve or muscle, and to vary this strength at pleasure. When a rheocord is introduced into a galvanic circuit, the current divides itself into two, the one of which we can transmit to the nerve, while the other returns directly to the battery. We have thus a nerve circuit and a battery circuit, and if we interpose resistance in the latter circuit, more electricity will pass through the former. The rheocord consists of a long wooden box. Along one side of this box there are two thick platinum wires, S_1 W_1, and S W, connected at S and S_1 by screws with the two brass plates S_1 with 1 and S with P. At σ σ they pass over a piece of ivory to the screws W and W_1. At one end, on the top of the box, there are six brass plates, 1, 2, 3, 4, 5, and 6, each of which is separated from the other by an interval, which may be readily filled up by a thick ivory-headed brass stopper. Along the surface of the box, and under the platinum wires, there is a piece of brass, Z, capable of sliding backwards or forwards, and having on its surface two hollow cylinders, A, made of polished steel and filled with mercury. These cylinders are pierced by the platinum wires, and the ends directed towards W_1 and W are tightly corked. This brass slide, therefore, forms a bridge between the two platinum wires, which are nowhere else connected by a conducting substance. The current cannot pass from S to S_1 except by going to the nearer cylinder in the direction of the arrow ⟶, and from the other cylinder to S_1, as indicated by the arrow ⟵. It is, therefore, evident that the amount of resistance offered by the platinum wires to the passage of a current of electricity may be modified by pushing backwards or forwards the brass slide. In proportion as it is pushed towards W_1, W, the resistance evidently becomes greater. Along the side of the platinum wires there is a graduated scale divided into millimetres, which may be used in comparative experiments. In order still farther to modify the resistance at pleasure, there are on the under surface of the cover of the box, in connection with the brass plates 1, 2, 3, 4, 5, 6, a series of wires of German silver, which are represented in fig. 11 by dotted lines, and which, after going up and down in the box, pass from the one brass plate to the other. When all the stoppers are placed between the brass plates, the German silver wires are not in the battery circuit. If, however, we remove the stopper between 5 and 6, the wire connecting 5 and 6 (bracketted at the other end of the figure, and marked X) is brought into the battery circuit, and thus the amount of resistance is increased. The same holds good with regard to the other stoppers. In connection with the brass plates S and 6 there is a short brass upright, each bearing two binding screws, P and Q. The wires from the battery *a a* are connected with the lower binding screws, while those going to the nerve *b b* are attached to the upper.

Mode of demonstrating Pflüger's experiment.—The limb of a frog, having been prepared by dissecting out the sciatic nerve, without injury, is fixed in a pair of brass forceps. The nerve is then stretched over two copper or zinc wires, carefully insulated, and provided with connectors, by which they are attached to two of the cups in a Pohl's commutator, the cross bars being present for the purpose previously described, that of enabling us to transmit a current upwards or downwards in a nerve at pleasure. Two wires are led from the commutator to the upper screws on the rheocord. The lower screws of the rheocord receive wires from the battery, and a key is introduced into the circuit, by means of which we can open or close it at pleasure. The connections having been thus made, we endeavour in the first place to stimulate the nerve by as weak a current as possible. This is effected by using one small Grove's cell and having all the brass stoppers of the rheocord in their places. By this arrangement there is almost no resistance in the battery circuit, and consequently a weak current is transmitted to the nerve. By means of the commutator, also, we are enabled to transmit the current along the nerve either in an upward or downward direction, and the result is to be observed on opening and closing the key. The strength of the current is now to be increased by using two or perhaps three of Grove's cells, and by removing one or two of the brass pegs in the rheocord. On opening and closing the key, and by moving the commutator, we now observe the effect of a medium current transmitted upwards or downwards along the nerve. The effect of a strong current is shewn by using five, six, or eight of Grove's cells, and by removing all the pegs in the rheocord. By carefully graduating the strength of the current, and operating upon at least 1¼ inch of healthy nerve, the results described at page 172 may usually be obtained ; but occasionally, from the fact that the nerve is irritable in frogs which have been long kept in confinement, it is difficult to obtain contractions in the order described by Pflüger and others.

Pflüger's experiment to shew that the nerve force accumulates intensity as it advances.—This remarkable fact may be demonstrated by stimulating a nerve close to the muscle, or at a short distance from it, when it will be found that a current too weak to cause contraction of the muscles when sent to a point close to the muscle, will cause powerful contraction when transmitted to a point at a distance from the muscle (p. 175). To succeed with this experiment, it is necessary to use a large frog so as to obtain a long nerve. This nerve is stretched across two pairs of wires, the wires in each pair being placed close together, and each pair being also separated by a distance of about an inch. The wires are placed in connection with a Pohl's commutator, to which also are attached wires from the secondary coil of an induction machine, a key being interposed in the battery circuit. We are thus enabled to transmit the current either near to, or at a distance from, the muscle ; and by diminishing or increasing the distance between the primary and secondary coil of the induction machine, we can graduate the strength of the current. The best method of making the experiment is, in the first instance, to remove the secondary from the primary coil to such a distance that no effect is produced when the nerve is stimulated either close to, or at a distance from, the muscle. Having then placed the commutator so that the current will be transmitted along the wires to the portion near to the muscle, the key is opened, and the secondary coil is gradually approximated to the primary, until a very feeble, almost imperceptible, contraction is produced. On now moving the commutator so as to transmit the current to the portion of nerve at a distance from the muscle, a very powerful contraction at once takes place, clearly demonstrating that the same amount of stimulus produces a greater effect when applied to a nerve at a distance from, than when applied near to, the muscle.

Experiment to determine the rapidity of the nerve current.

This problem, which has received the attention of many physiologists, has now been satisfactorily solved by the labours of Helmholtz and Du Bois-Reymond. The necessary instrument is termed a *myographion*, of which there are several varieties, but the one generally used is that employed by the two distinguished physiologists just mentioned. A sectional view of this instrument is seen, Plate XX. fig. 1, and the arrangement of the apparatus for the experiment, will be understood by referring to the diagrammatic sketch in Plate XX. fig. 3.

Mode of calculating time by tracings on a revolving cylinder.—Before describing the Myographion, the student must understand this important method, which is applied to many experiments in practical physiology. Suppose a cylinder, worked by clockwork, or even steam power, makes one revolution in a minute, and its surface is divided into sixty equal parts by sixty vertical lines at equal distances from each other, the distance between two lines evidently represents in time one second. By measuring the circumference of any cylinder, and by observing the time occupied by one revolution, we can thus calculate the time represented by the distance between any two points in the circumference. This principle, which we owe to Th. Young, 1807, is taken advantage of in the myographion. It is necessary that all revolving cylinders go smoothly, and at a uniform rate. This is attained by a fly-wheel, or a centrifugal apparatus attached to it.

Description of the Myographion.—The myographion, although a very complicated instrument, consists essentially of three parts: 1st, arrangements for holding a muscle having the sciatic nerve attached, the latter being connected with electrodes; 2d, clockwork for moving a revolving cylinder with a certain measured rapidity; and 3d, arrangements for stimulating the nerve at the particular moment when the cylinder has reached a known velocity.

(1.) The muscle consists of the gastrocnemius (figs. 1 *j* and 3 *b*) attached to the femur, and having the sciatic nerve in connection with it. Into the *tendo Achillis* is inserted a small hook, from which is suspended a long thin iron wire, *k*, the latter being in connection with a lever apparatus, *l l*. This lever, the fulcrum of which is on the top of the pillar F, is balanced behind by a movable weight, *m*, and has at its other extremity a rectangular arm, O, bearing the stylette P. This stylette is opposite the cylinder B, and it is evident, on examining the plate, that if the muscle contract, it will elevate the lever, and the stylette P will make a mark upon the cylinder. At the top of the figure will be seen various contrivances for accurately adjusting the muscle with reference to the lever. The strong brass pillar E supports a square glass chamber, in which the muscle is placed, and in which it can be kept living and moist for several hours, by placing on the inner surface of the glass a few bits of blotting paper dipped in warm water. The floor of this chamber is made of vulcanite, and is perforated by a hole between *r* and *r*, so as to permit the passage downwards of the iron wire *k*, connecting the *tendo Achillis*, with the lever. When the apparatus is being used, in order as much as possible to exclude air, and keep the muscle moist, the hole in the vulcanite floor is almost closed by two semicircular pieces of glass, *r r*, having a small excavation on the straight border of each, so that, when in apposition, only a small round opening is left. The brass forceps may be elevated or depressed by moving them upwards or downwards in the socket marked *c*. This socket has a universal movement in the air-tight box *i*, *e*, *g*, and may itself be regulated by the screws *h* and *e*. Into the bottom of the moist chamber we have usually four double binding screws, three of which are seen in Fig. 1, marked S, S, S, and S′, S′, S′. These are for the purpose of attaching wires to the muscle within the moist chamber.

(2.) The motive power of the clock-work is a heavy weight attached to a strong cord, *a*, wound round a drum, and which passes over a pulley. The situation of the clock-work is seen at A, and on its surface there is a small dial, *b*, so regulated, that when the machinery is in operation, the hand moves one degree for every ten revolutions of the cylinder.

(3.) The most important part of the apparatus is the arrangement for stimulating the nerve exactly at the moment when the cylinder has reached a certain definite velocity. That velocity is usually fifteen revolutions in the second. This part of the apparatus will be best understood by referring to Plate XX. fig. 3, while at the same time further attention is given to Fig. 1. Underneath the lever, and securely fixed to the stand D D of the instrument, there are two brass uprights, Fig. 1, *t*, and Fig. 3, *k*, each bearing a rectangular arm, and each having a binding screw. The two arms come into close apposition with each other at Fig. 3, *g*, but do not touch, the connection between them being established by a strong steel spring attached to one of them. This bridge-like part of the apparatus is introduced into the battery circuit, which also includes the primary coil of an induction apparatus. This will be understood by referring to Fig. 3, where we see *l* the battery, *m* the primary coil of the induction machine, *k* and *i* the piers of the bridge, and *g* the steel spring establishing a connection between them. It is evident, therefore, that when the steel spring completes the bridge, the galvanic current from *l* will pass to *m*, thence to *k*, thence along the bridge *g*, and from thence by the wire *i* back to the battery *l*. But if the bridge *g* be broken by the elevation of the spring, it is also evident that, in accordance with the principles of induced or Faradic electricity, at that moment a secondary current will be induced in *n*, the secondary coil, which secondary current is employed in stimulating the nerve.

The next part of the mechanism is that by which this is accomplished exactly when the cylinder attains a velocity of fifteen revolutions in the second. It is done by means of a rectangular arm of brass marked in Fig. 1 $\pi' \pi$, and in Fig. 3 by *h*, bearing at the end farthest from the cylinder, and immediately underneath the spring, a quadrant or arc of brass. When this arm is pushed to the left side, it will be found that the quadrant moves through a distance of a quarter of a circle and elevates the steel spring. It is, therefore, necessary that the arm be pushed over at the proper moment, so as to break the primary circuit. For this purpose, there is an ingenious application of the principle of centrifugal force. Underneath the cylinder B, but on the same steel axis, L L, there is a round brass box, C.

This box, therefore, revolves with the same rapidity as the cylinder, and any two points on the surface of the cylinder and box will always be in the same vertical line. On removing it, and looking into its interior, we see two brass weights, *e* and *c*, as represented in Plate XX. fig. 2, one of which, *e*, is immovably fixed in its position, while the other, *c*, is loose, but in connection with a steel spring, *d*, which keeps it in its place. Connected with the weight *c* there is a curved steel spring or catch, *b*, having at the end of it a hook, which is fixed into a notch on a piece of steel, *a*, bevelled at the point. This piece of steel, *a*, we may term the "out-springer," because, if not restrained by the steel spring *b*, it would tend to dart outwards in the direction of the arrow <——, the motive power being the wire spring coiled round the end next *d*. When, however, the box is rotated by the machinery, the weight *c* being movable, tends, by centrifugal force, to pass outwards towards the circumference of the box, in the direction of the dotted lines ∴, and when it reaches the side of the box, which only takes place when the latter is making fifteen revolutions in the second, the spring *b* has been so altered in position that its catch is removed from the out-springer *a*. This latter being thus released, darts out, and strikes against the end of the rectangular arm already described, pushes it to one side, and thus breaks the bridge by elevating the steel spring *g*, Fig. 3. When this occurs, as already explained, there is an induced current in the secondary coil *n*, Fig. 3, which is transmitted to the nerve.

There is still another part of the instrument to be described, that by means of which the stylette is applied to the cylinder at the proper time. It is evident that it must not be allowed always to be in contact with the cylinder, because it would, in the first place, by friction, interfere with its velocity; and, in the second, a number of indistinct marks would be produced on it, which would injure the proper tracing desired. This is avoided by keeping the stylette within a short distance of, but not touching, the cylinder until the moment of time (the fraction of a second), *immediately after*, the out-springer has come out of the brass box. The arrangement for doing this consists of a bar of brass having the shape ╷———╵ (Plate XX. fig. 1, v' and $v_{\prime}$), placed above the brass box, and to the right of the common axle, L L, of the cylinder and the box, having the one end bent at right angles upwards, and the other downwards, v' and $v_,$. This piece of brass v' $v_,$ moves on an axle τ τ''. The right hand extremity of $v_,$ $v_,$ supports a lever above it, a moving on a fulcrum, τ ρ to the end of which, p, there will be seen a very fine thread passing downwards to φ the end of a balance, V. To the other end of this balance, a short rod terminating at ε (near the base of the pillar F), has attached to it another thread which ascends to v, and there passing over a small pulley, goes onwards to be inserted into the end of the stylette P. When, therefore, the lever is supported by the piece of brass v' $v_,$ the thread is kept tense, and thus the stylette is prevented from touching the cylinder, and the rectangular arm is on a higher level than the end of the out-springer. (See Fig. 1, ρ and ϖ.)

But if we now examine the figure, we shall see near the axle bearing the box and cylinder, a small triangular projection, β. This is the other end of the out-springer (Fig. 1), and a (Fig. 2), projecting through an opening in the lid of the centrifugal box. When, therefore, the out-springer leaps out, the end next the axle β first comes against the piece of brass v' and $v_,$ knocks it from under the lever a, so that the thread is relaxed, and the stylette comes into contact with the cylinder. Not only so, but the same relaxation of the thread allows the rectangular arm to fall down vertically to a level with ρ the end of the out-springer. This occurs immediately after the out-springer has passed the end of the arm, so that when another revolution is made, it strikes against the end of the latter, and thus breaks the bridge in the primary circuit, by elevating the steel spring at g in the manner already described (Fig. 3).

Mode of making the experiment.—Having now explained the mechanism of the instrument, we must next describe the arrangements for the experiment, with the aid of the diagram, Fig. 3. Here we have a muscle, b, attached to a femur, which is held securely by the forceps a r. In connection with the muscle, we have the nerve c stretched on two pairs of wires at a certain distance from each other, say two inches. The problem is to find the length of time the nerve-current occupies in passing from q to r. The *tendo Achillis* is attached by a hook to the lever e, bearing a stylette pressing a cylinder, which is carefully smoked in the flame of a turpentine lamp. On the same axle, and underneath the cylinder, is the centrifugal box f. The primary circuit is now completed as follows: A wire is carried from the positive pole k of the battery, l to m, the primary coil of an induction machine. From thence it passes to k, one of the piers of the bridge, thence along the bridge, traversing the steel spring g, and from thence along the wire i, back again to the battery i. The secondary coil of the induction machine is now connected with Pohl's commutator at n'', n'', from which two wires near o, 1, 2, pass to the portion of nerve at q, at a distance from the muscle, while those near p, 3, 4, pass to r, close to the muscle. By moving the commutator we can thus transmit the induced current from the secondary coil either to the portion of nerve at q or at r. The arrangements having thus been made, the commutator is placed so as to send the current first to a portion of nerve at a distance from the muscle, as shewn in Fig. 3 at q. The clock-work is now set in motion; and when the cylinder has acquired a velocity of fifteen revolutions in the second, a sharp click is heard, caused by the out-springer striking away the rectangular arm, and the muscle at that moment contracts. We now reverse the commutator, so as to stimulate the nerve near the muscle (Fig. 3, r), and we arrange the myographion for another tracing. This is done by gently pushing in the out-springer by a little button seen on the side of the brass box, elevating the lever ə, and introducing beneath it the piece of brass v', $v_{,}$, so as again to remove the stylette from the cylinder. We also readjust the rectangular arm, by elevating it. It will be found that the arm, when struck away, is firmly held down by the spring catch β, so as to secure the muscle receiving only *one* induction shock. Everything being again ready, the operation is repeated in the same way, and a tracing obtained of the muscular contraction caused by stimulating the nerve near the muscle. The smoked cylinder is now carefully removed, when there will be found on it a slight tracing like what is shewn in Plate XX. fig. 7, but in much more delicate lines than there represented. Here we have first a basement line, a b, and two curved lines proceeding upwards, the one, c e, being produced by the contraction of the muscle when the nerve was stimulated close to it, while the other, d f, represents the contraction when the stimulation was applied at a distance from the muscle. The distance, then, between the points, c d, at which these curved lines leave the horizontal line, indicates the length of time the nerve-current took in passing from the point stimulated at a distance to the point stimulated near the muscle, that is, along a length of two inches. It follows that as we know the circumference of the cylinder and its velocity, there is no difficulty in calculating the time it represents.

Calculation.—The data given are—(1.) Length of nerve examined, two inches; (2.) Distance between the commencements of the two curved lines, 1-6th of an inch; (3.) Circumference of cylinder, six inches; and (4.) velocity of cylinder, fifteen revolutions in a second. $15 \times 6 = 90$, the number of inches of cylinder which pass before the stylette in one second. $90 \div$1-6th$=$1-540th of a second, that is, the distance 1-6th of an inch on the cylinder represents in time the 1-540th of a second. Now the 1-6th of an inch on the cylinder indicates the length of time the nerve-current took in travelling along two inches of nerve. Therefore the nerve-current travels two inches in the 1-540th of a second. But two inches are the 1-6th of a foot; therefore the current will travel a foot in 6-540th of a second, that is, 1-90th of a second, or 90 feet in one second.

There are many other details in the management of this instrument which can only be understood by careful study and practical manipulation.

Other myographions have been used by Du Bois-Reymond, Æby, and Marey, but the one now described is the most accurate. No one can study it without being profoundly impressed with the great amount of ingenuity and skill displayed in its construction.

EXPERIMENTS ON THE CIRCULATION.

Before making any experiments on the circulation, the student should study the phenomena of hydrostatics and hydrodynamics described at p. 114, and the phenomena produced by injecting water through non-elastic and elastic tubes.

1. *Non-elastic tubes.*—For this purpose a glass tube, having a diameter of 1-8th of an inch, and about eight feet long, may be employed. On driving water through this tube by means of an india-rubber syringe, it will be found that the fluid will pass from the other end of the tube in a series of jets, or *per saltum.* In this case, the tube being almost non-elastic, there is no wave-like motion. If, however, an india-rubber bag be attached to the end of the glass tube farthest from the syringe, it will then

be seen that the jet-like efflux of the fluid has now been converted into a more or less uniform flow.

2. *Elastic tubes.*—In order to demonstrate the effect produced upon a current of fluid forced through an elastic tube, about eight or ten feet of good india-rubber elastic tubing is required. On injecting water through it, the fluid will not pass out in a series of jets, or *per saltum*, but with a uniform flow. It should now be demonstrated that the elasticity of the tube has the property of converting the impulse of the syringe into a wave-like motion, which may be done by means of an apparatus devised by Marey, termed a *triple sphygmograph.*

Marey's triple sphygmograph.—This consists of an arrangement of three light wooden levers of equal length moving on a delicate fulcrum placed near one end of each lever. These levers are carefully fixed, by means of screws, to a wooden upright, so that each lever is about 1¼ inch from the other, but in the same vertical plane. To the free end of each lever there is attached a small pen or brush, so that when brought into contact with a revolving cylinder, any movement they make is registered in the form of a curve. The apparatus being thus arranged, the india-rubber tubing is brought under the lowermost lever, about one foot from the syringe, and is placed in a grooved brass support, so that the lever rests lightly upon it. About four feet of the tube is now carried round the rings of two retort stands, fixed on their supports about a foot in height, and then it is brought under the second lever in the same manner. Other three feet of tube are carried over the rings of the retort stands, and after passing under the third lever, the end of the tube is conveyed into a vessel for receiving the water. Thus we have three levers placed at different distances on the india-rubber tubing. On now carefully bringing the free ends of the levers against a smoked cylinder, caused to revolve by clock-work, and forcing water through the tube at regular intervals from a syringe, we obtain on the cylinder three exactly parallel and comparable traces. The tracing produced by the lever next the syringe will shew a series of waves with a bold vertical line, a somewhat abrupt summit, and a gradual descent. That obtained by the second lever will shew waves with a more gradual ascent, a more rounded summit, and a gradual descent; while the tracing made by the third lever will manifest only minute waves. Thus it may be demonstrated that the original force of the impulse, and the extent of the vertical movement of the lever diminishes with the increase of distance from the impelling organ, whilst the time of impulse remains the same. Other experiments to shew how the pulsatile is converted into a uniform flow of fluid, as in the capillaries and in aneurisms, with rigid or elastic coats, may also be demonstrated with this instrument.

Experiments on the pulse.

These may be made by means of various instruments.

Vierordt's sphygmograph (from σφυγμὸς, the pulse; and γϱάφω, I write).—The first form of this instrument was made by Vierordt, and consisted of a lever capable of being accurately balanced by shot or sand placed in a cup or cups situated near one end. From the lower surface of the lever, a little rod descended furnished with a small button, which was allowed to rest upon the artery. This rod was attached to the lever, close to the fulcrum, so that a slight movement of it produced an extensive movement of the long arm of the lever. This latter was brought in contact with a revolving cylinder. Tracings were thus obtained, but the inertia of the lever was too great for the force of the circulation, and the periods of contraction and dilatation of the ventricle were not accurately marked.

Marey's sphygmograph.—The principle of this instrument is exactly the same as that of Vierordt's, but it has the advantage of having a very light lever, and of being altogether a much less cumbrous instrument. A view of this instrument is seen in Plate XXI. fig. 13, in which it is represented as attached by bands to the left arm, so that a tracing may be obtained of the pulsations of the left radial artery. A diagrammatic view of the essential parts of the instrument is seen in Fig. 14. It consists of a very light wooden lever, Fig. 14, *a b*, moving on a fulcrum seen at *k*. Underneath this lever there is a fixed bar, *c d*, to the under surface of which, near *c*, there is attached a steel spring, *e f*, bearing at *f* a button padded with leather or ivory, which rests upon the pulse. From the upper surface of the button *f*, there passes a vertical screw, *f i*, which ascending through a slit in the fixed bar *c d*, bears on it a small steel projection, which when the screw *f i* is elevated, also raises the lever *a b*, in the direction indicated by the dotted lines *g h*. The lever is brought down to its original position, *a b*, by a delicate steel spring marked *k*. It is evident, on studying Fig. 14, that very delicate movements of the button *f* will produce considerable extent of movement of the lever *a b*, at the point *a*. This point bears at *a* a small pen, slightly bent, which touches the side of a card or plate of smoked glass, or smoked gelatin or mica, which is made to move gradually forward in the direction of the arrows ——→ ——→ by clock-work (see Fig. 13). The degree of pressure by the button *f* (Fig. 14), on the pulse may be regulated by the screw *i f* (Fig. 14), seen also at *a* (Fig. 13.) The objection to this form of sphygmograph is, that there are no means of accurately measuring the pressure of the button on the pulse. This has now been accomplished, in recent instruments, by means of a screw which regulates the pressure of the spring (Fig. 14) *k*. The head of this screw is divided into equal parts, each division representing so much pressure in grammes-weight, so that in taking tracings of the same pulse at different times, we are enabled to use exactly the same amount of compression upon it. Other sphygmographs have recently been constructed by Mayer & Meltzer, of London, which may be easily adjusted to the wrist by a bracelet, and in which the tracing is obtained on a piece of mica surrounding a small revolving cylinder. For a description of the pulse, and of the meaning to be attached to a sphygmographic tracing, see pp. 216, 217.

The cardiograph of Marey.—A view of this apparatus is seen in Plate XXI. fig. 16, by which Marey was enabled to obtain three tracings simultaneously from the right auricle, the right ventricle, and the pulsation of the heart through the walls of the chest. It consists essentially of (1.) a registering apparatus; (2.) small oval sacs or ampullæ, made of india-rubber, for receiving the impulse in the vessels or cavities of the heart; and (3.) an apparatus termed a *tambour* or drum, for communicating the impulse to a lever. The registering apparatus is a cylinder, A, E, moved by clock-work, on which there is enrolled a long band of paper. The levers *lc*, *lv*, *lc*, placed one above the other in the same plane, touch the paper by the point of the pen, which terminates each (Fig. 15, *l*, P). The ampullæ for receiving the impulses are seen in Fig. 16, *c*, *v*. These communicate with the tambours by long elastic tubes, containing air, marked *tc*, *tc*, *tv*, which are supported by two iron stands, seen one on each side of A 3. A separate view of one of the tambours is seen in Fig. 15. It consists of a shallow drum, T, on the surface of which there is placed a thin circular plate of aluminium, *a*. This supports, and is attached to, a short upright in connection with the lever *l*, *l*, P. There is an arrangement seen above E for moving the drum backwards or forwards, and there is also a screw by which we can move the position of the aluminium plate. A short brass tube communicates with the bottom of the drum, or opens into its side, as seen at *b*, to which the elastic tube is fixed, so that the slightest pressure of the air in the drum communicated through the elastic tube produces a movement of the lever. The advantage of this apparatus is that it is easy of application, and its disadvantage is that, in consequence of the great amount of elasticity of the india-rubber drum head, the lever is apt to produce a number of secondary curves instead of one firm, well-defined line. It may be applied to the registration of many other kinds of movement.

The Sphygmoscope of Scot Alison.—This instrument, as its name indicates, is an apparatus for shewing the movements of the pulse to the eye. It is a truncated cone made of brass, the base consisting of a piece of highly elastic india-rubber. To the truncated end of the cone there is a piece of india-rubber tubing passing to a glass tube, bent near the same end to an angle of about forty-five degrees. The apparatus being nearly filled with a coloured fluid, such as infusion of litmus, it is evident that the slightest impulse communicated to the elastic base of the cone, will be at once seen by an elevation and depression of the coloured fluid in the tube.

The Sphygmoscope of Czermak.—This instrument consists of a small rectangular mirror, so fixed by its upper extremity as to move freely when the lower extremity rests upon the pulse. If the instrument be now fixed to the arm so that the free end of the mirror rests on the radial artery, and a strong ray of light be reflected from the mirror upon a vertical scale, the slightest movement of the mirror will be manifested by a great extent of movement of the spot of light on the scale. Thus the movements of the pulse may be exhibited to a large audience.

The Sphygmosphone of Upham.—This apparatus, seen in Plate XXI. fig. 17, is for the purpose of enabling the ear, by means of electric bells, to determine the frequency and rhythm of the cardiac and radial, or femoral pulsations. It may be divided into two parts: (1.) An arrangement for receiving the impulse, and by means of this impulse, breaking an electric circuit; and (2.) an apparatus for ringing one or other of a pair of electric bells when the circuit is broken.

The arrangement for receiving the impulse from the apex or base of the heart through the thoracic wall, and from any large artery, consists of two small bell-shaped glasses, *l*, *m*, having the mouth of the bell covered over with thin india-rubber. From the other end of the bell we have two elastic tubes which are attached at their other extremity to similar bell-shaped glasses, also closed by india-rubber, marked *i* and *i′*. When these tubes and bells are carefully filled with water, it is evident the slightest impulse received on the india-rubber surfaces of *l m* will be communicated to those of *i* and *i′*. Immediately over *i* and *i′* there are two brass bars moving upon hinges, and having their free ends directed inwards, and resting upon a square piece of brass, as seen at *k* and *k′*. Attached to the under surface of each of these bars there is a round metallic plate, which rests on the india-rubber surface of the glasses *i* and *i′*. By this arrangement, a very slight impulse communicated through the fluid in *l i* and *m*, *i′*, will elevate the brass bars and break the contact at *k* and *k′*.

The other portion of the apparatus consists of two electric bells, *a* and *b*, which are rung by the hammers *c* and *d*, attached to the keepers *e* and *f* of the two electro-magnets *g*. The current of electricity from two of Smee's elements is conveyed into the apparatus by the wire *p*, passes through both electro-magnets, which, by attracting their keepers *e* and *f*, withdraw the hammer *c* and *d* to a short distance from the bells *a* and *b*. The point of contact between the two electro-magnets, as already explained, is at *k* and *k′*. If, therefore, an impulse be communicated through the apparatus *l i* sufficient to break the contact at *k*, by elevating the brass bar, the keeper of the electro-magnet *g* is released, and the bell *a* will ring, only one stroke of the hammer *c* being given. In the same manner the bell *b* is rung through the influence of *m i′*. By means of this apparatus the interval of time between the cardiac and radial pulsations may be rendered evident to an audience by the different tones of the bells; and as the contact-breaking part of the apparatus may be in Edinburgh, and the electro-magnetic apparatus in London, a demonstration might be given by telegraphic wires to a London audience of the cardiac and radial pulsations of an individual in Edinburgh.

Experiments to measure the rapidity of the circulation.

This may be estimated roughly by means of two instruments.

1. *Hæmatachometer of Vierordt* (αἶμα, blood; τάχος, speed; μετρον, measure).—The essential part of this apparatus is seen in Plate XXI. fig. 20. It consists of a rectangular chamber, A B, the sides of which are made of glass. This chamber is furnished with two nozzles, *a* and *b*, for insertion into an artery which has been cut across. In the anterior part of the chamber there is a very light vertically-suspended pendulum seen at *c*, placed close to the point of entrance of the current of blood into the chamber. This will of course move the pendulum from the perpendicular as seen at *e*, and the amount of this deviation will indicate the velocity of the current. To this apparatus is suspended a long lever placed above the box A B, which is moved by a rack and pinion arrangement by the hand of the experimenter, synchronous with the movements of the pendulum. The free end of the lever is provided with a pen or brush, so that a tracing may be obtained on a revolving cylinder. The objection to this instrument is, that the conditions of a square box are different from those of a blood vessel; the inertia of the pendulum has to be overcome, the accuracy of the tracing depends on the quickness of the eye and steadiness of hand of the experimenter, and the whole apparatus is large and difficult of application.

2. *Hæmadromometer of Volkmann* (αἶμα, δρομος, a race-course, μετρον).—This instrument is seen in Plate XXI. figs. 18 and 19. It is composed of a U-shaped tube, *d*, *e*, of a given length, having attached to it a scale, graduated in millimetres. The ends of this glass tube fit at *d* and *e* into a brass apparatus, *a*, *b*, having nozzles at *a* and *b*, which are inserted into the cut ends of the artery. This part of the apparatus is furnished with a screw, or stop-cock, bearing a rectangular arrangement of brass tubing, so that by turning it the blood may be caused to flow directly from *a* to *b*, as seen at Fig. 18, or along the U-shaped tube, as seen in Fig. 19. The experiment is thus performed :—The artery is laid bare, and the circulation through two inches of its extent is controlled by two strong spring forceps fixed on it at that dis-

tance from each other. It is then divided, and the nozzles *a* and *b* inserted into the cut ends, and firmly secured by ligatures. The stop-cocks are arranged, as seen in Fig. 18, and the spring forceps being removed, the blood will, of course, flow directly from *a* to *b*. The experimenter being provided with an accurate chronometer, on a given signal the stop-cock is turned, so that the blood will flow along the U-shaped tube, as seen in Fig. 19, and the time it occupies in passing from *d* to *e* is noted. The length of the U-tube being known, the rapidity of the circulation is, of course, thus determined. The U-tube, however, being almost non-elastic, and in no way fulfilling the conditions of a living artery, the determination of the rapidity must be held as only approximative.

Experiments to measure blood-pressure.

1. *Hæmadynamometer of Poisseuille* (αίμα, blood ; δυναμις, power ; μετρον, a measure).—This instrument consists of a long U-shaped glass tube, Plate XXI. fig. 21, *a*, *b*, of uniform calibre, and having the inner surface exceedingly smooth. Into the tube some clean mercury is placed, which comes to a level in the two limbs as seen at *d e*. Attached to both limbs there is a graduated scale for registering the oscillations of the mercurial columns. From the limb of the tube at *a*, there passes the curved leaden tube *q l m*, having an air hole at *n*, a joint at *l*, a stop-cock at *o*, and a nozzle placed transversely at *q*. This bent tube fits the U-shaped tube at *a* very accurately, and there is a collar, *m*, which is screwed over the connection so as to make the junction perfectly water-tight. The transverse nozzle at *q*, is represented of larger size in Fig. 21, *b*. It consists of the tube *a b*, Fig. 21, for insertion into the artery, and of the short tube *c* placed at right angles to *a b*, which fits accurately into the end of the leaden tube at *q*. The whole of the leaden tube *q l m*, and the upper limb of the glass tube *a d*, to the surface of the mercury at *d*, is carefully filled with a solution of carbonate of soda, which is used because it has the property of preventing the coagulation of the blood in the nozzle *q*. In accordance with the law that fluids press equally in every direction, the pressure of the blood passing through the nozzle *q*, is communicated latterly through the column of the solution of carbonate of soda to the surface of the mercurial column at *d*. The blood does not flow into the leaden pipe

q l m, but passes straight through the nozzle *q*, and the increase and diminution of pressure is indicated by the movements of the mercurial columns at *d* and *e*. The amount of this pressure is measured by the scales *c*, Fig. 21. If the mercurial column be depressed one-fourth of an inch at *d*, it will be elevated the quarter of an inch at *e;* the total pressure, therefore, being one-half inch of mercury.

2. *Kymographion of Ludwig* (κυμα, wave, γϱαφω).—This instrument, as seen in Plate XXI. fig. 21, is the apparatus just described, together with an arrangement for registering the movements of the mercurial column. This is effected by means of a very light glass float, *f*, having attached to it a long fine steel wire, *f g*, at the top of which there is a steel rod bearing a stylette, *i*. From the upper end of the rod *g*, a delicate thread passes upwards to the top of the frame *h h*, moves round a small pulley, and suspends a weight, *k*, which acts as an equipoise to the glass float *f*. The rod *g*, bearing the stylette, moves in the same vertical plane, being kept in position by two fine steel wires in the frame *h h*. This apparatus enables us to obtain very delicate tracings, the movement of the mercurial column being communicated to the float, and by the latter to the stylette. To the left of Fig. 21, a revolving cylinder, *b*, is shewn, moving upon an axle, *a c*, and having a stylette, *d*, applied to its surface.

When it is desirable to make an experiment, with the view of determining the amount of blood pressure, the leaden tube must, in the first place, be carefully filled with a solution of carbonate of soda. For this purpose we require several syringes, having nozzles of various sizes. The stop-cock at *o* is perforated through the top, so as to permit the escape of air, and it is furnished with a small stopper for preventing the escape of the fluid. By means of this stop-cock we can allow the blood pressure to be communicated to the mercurial column, or we can shut it off at pleasure. The leaden tube is to be filled by inserting the nozzle of a syringe into the hole in the stop-cock *o*, the latter being turned so as to prevent the escape of the fluid through the nozzle *q*. Thus we fill the tube *l*, *m*, and usually part of the tube *n*, *m*, *d*,—the air escaping by the air-hole *n*. We next introduce the point of the syringe at *n*, and endeavour to fill the remainder of the tube. When we have done so, we must rapidly remove the syringe, and introduce a stopper into the air-hole *n*, taking care to bring the mercury in the two limbs of the U-tube to a level. The nozzle is introduced into the artery in exactly the same way as already described with reference to the Hæmadromometer. To obtain an accurate tracing, three things must be carefully attended to :

1. The blood must be prevented from coagulating in the nozzle introduced into the artery, and occasionally it may be necessary to remove the nozzle, and to clean it out by a fine wire or bristle, after properly securing the artery.

2. The float must move freely in the glass tube. Before using the apparatus, the tube ought to be carefully dried with a piece of cotton attached to a long wire, and the mercury employed must be perfectly free from dust or moisture. Before using the latter, it should be carefully filtered through a minute perforation in a sheet of white writing paper, and be dried by placing it in a porcelain capsule for five or ten minutes before the fire.

3. The stylette must mark the cylinder with as little friction as possible. This is accomplished by attaching to its point a small finely-pointed brush, which is kept wet with ink of sufficient fluidity ; or by means of a small conical glass, fixed to the stylette, having the apex drawn to a very fine point, perforated and bent so as to barely touch the cylinder. A small quantity of ink is placed in the glass, and passes in a very fine stream through the perforation in the bottom.

In addition to the curve produced by the movements of the recording apparatus, it may be serviceable to have two other tracings made at the same time, one being a horizontal line, drawn by a fixed stylette, and the other a rapid but regular tracing of a series of equally sized secondary curves, produced by another stylette in connection with a magneto-electric apparatus working with great regularity. In the event of numerous experiments being required in any particular investigation, the whole apparatus should be permanently fixed to a table, which is also used as the operating table, and on which the animal lies.

Experiments on Respiration.

1. *Expiration of carbonic acid by the lungs.*—This may be readily demonstrated by breathing through a glass tube into lime-water. The lime-water becomes milky from the formation of insoluble carbonate of lime. The amount of carbonic acid expired may also be determined by causing an individual

to breathe for an hour air which has been carefully purified by passing it through caustic potash. He must inspire this pure air and expire through a solution of caustic potash, the strength of which is known, and which may be weighed. The increase in weight, due to the carbonic acid, indicates the amount of the latter ; or the amount of carbonic acid may be calculated, by the chemical rules of equivalence, from the amount of carbonate of potash formed.

2. *Expiration of aqueous vapour by the lungs.*—The amount of aqueous vapour may be estimated by breathing air (dried by passing through sulphuric acid) through an apparatus consisting of several U-tubes containing chloride of calcium, or pumice-stone steeped in sulphuric acid. The increase in weight will indicate the amount of aqueous vapour expired in a given length of time.

3. *Mode of measuring the quantity of air in inspiration and expiration.* (See pp. 228, 229.)—This is done by means of instruments termed *spirometers.*

(1.) *Spirometer of Mr Hutchinson* (*spiro,* I breathe ; μετϱον). —This is essentially a gasometer, consisting of an outer cylinder, having introduced at its base a pipe, leading from a mouthpiece, and rising in the centre of the cylinder nearly to its brim. Into this cylinder another one is inverted, which is carefully balanced by two cords passing over two pulleys, and suspending two weights. When air is forced into the tube already mentioned, and the outer cylinder contains a certain quantity of water, the inner cylinder rises. The amount of air is indicated by a scale, graduated into cubic inches, which is attached to the inner cylinder, and consequently rises with it, the amount being marked off by an index fixed to the outer cylinder. The inner cylinder is provided with a stopper, by removing which, and forcing down the cylinder, we are enabled to expel the air. This instrument does not give accurate scientific results—the muscular strength of an individual influencing the amount of air forced from the lung, independently of the pulmonary capacity.

(2.) *The Anapnograph of Bergeon and Kastus* (ἀναπνεώ, to draw breath ; γϱάφω).—The principle of this instrument is quite different from that of Mr Hutchinson. It is seen in Plate XXI. fig. 22. It consists of two parts : first, an arrangement of clock-work for carrying a sheet of ruled paper, P C, placed in a brass box, M N ; and second, of another apparatus consisting of a rectangular box, R, into one side of which we have fixed an india-rubber tube, terminating in a cover for the nose, as seen at O. The other side of the box is quite open, as at V. A section of the box is seen at C. In its interior there is a vertical plate of aluminium, moving freely on a hinge, at the bottom of the box. This plate, seen in C, 3—2 acts as a valve during inspiration and expiration through the box. In inspiration the valve is drawn towards the nose, as indicated by the dotted line in C, 3—4 ; and in expiration it is forced in the opposite direction. To the edge or border of this valve there is attached a long light lever, K, having at its free end a pen, P, which, as the lever is moved by the valve, makes a tracing upon the paper. It is important to observe, as will be seen on examining C, that when the valve is forced from the nostrils in expiration, the pen point will move in the opposite direction ; and the reverse holds good in the case of inspiration. The whole of the tracing on the left of the median line of the paper, therefore, represents the curve of expiration, while that on the right represents that of inspiration. Thus we obtain a tracing of the inspiratory and expiratory curves. The amount of air of inspiration and expiration is calculated by having the paper carefully divided into squares, so that in ordinary respiration sixteen squares represent half a litre of air, while in forced respiration, four squares represent only half a litre. Thus by counting the number of squares within the curve, we obtain a knowledge of the amount of air. For ordinary respiration the apparatus is as shewn on Fig. 22, and the pen hangs loosely. In this condition forced respiration would drive the pen point beyond the margins of the paper, and perhaps damage the instrument. To obviate this, by turning the small button B, seen near the top of the box, pushing it downwards in a little slit, and again fixing it, the lever is rendered much less easily moved. This instrument is easy of application, and is more accurate than that of Hutchinson.

EXPERIMENTS ON SIGHT OR VISION.

The practical experiments which may be performed with reference to sight are so numerous that we can only select a few of the more important.

1. *Inversion of the image upon the retina.*—This may be illus-

trated by the student examining the inverted image upon the ground glass plate in an ordinary photographic camera. It may be also done by taking the eye of an ox newly killed, or still better, that of an albino rabbit, carefully separating the sclerotic from its posterior surface, and fixing it in a hole in a shutter, the pupil being directed forwards, while the observer is in the dark room examining the retina.

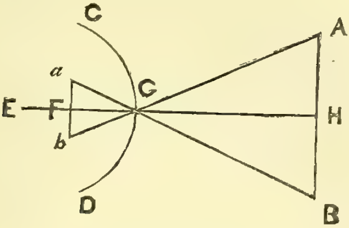
2. *Action of the muscles of the eye-ball.*—The *ophthalmotrope of Reute* (οφθαλμος, the eye ; τροπη, a turn). By means of this instrument, seen in Plate XXI. fig. 23, we are enabled to study the actions of the muscles of the eye-ball. It consists of a wooden box, *h*, supported by levelling screws, *i k*. From the surface of the box there rises a brass pillar, *g*, bearing a framework in which there are mounted the accurate models of two eye-balls. These latter consist of box-wood frames, having passing through their centre a brass tube, bearing on its anterior part a glass, representing the cornea, behind which there is a diaphragm, like the pupil, while its posterior end consists of a disc of ground glass, which stands for the retina. The six muscles acting upon each eye-ball are represented by as many delicate silk cords, accurately fixed to their proper position on the eye-ball. From thence they pass backwards through two brass plates, *c d*, then over a number of ivory pulleys downwards towards two scales, *f f*. The back of one of these scales is seen in Fig. 23, A. Each cord has attached to it a small piece of tinfoil, which serves as a pointer. The silk cords are ultimately attached to a roller in the box *h*. The peculiar position and direction of the superior oblique muscles of the eye-ball are imitated by a movable arm seen near the inner surface of the eye-ball *a*. By turning with the fingers the eye-balls of this ophthalmotrope, the action of the various muscles may be observed, and the angles formed by the lines of direction of the muscles measured. Numerous other experiments may be performed with it. By placing a wax candle eight or ten feet in front of the ophthalmotrope, the position of the inverted images on the retinæ, corresponding to any given direction of the visual axes, may also be studied.

Measurement of the Curvatures of the Cornea and Lens.

The cornea being a transparent structure, acts both as a lens and as a convex mirror. It acts as a lens by refracting to a slight extent rays of light passing through it, and it acts as a convex mirror by reflecting rays of light from its surface. It is the latter property that is taken advantage of in the method of making accurate measurements of its radius of convexity.

Formation of images by convex mirrors.—The image produced by a convex mirror is an erect image apparently placed behind the mirror. This will be understood by referring to Plate VIII. fig. 21. Here A P is a convex mirror, and C is the centre of the circle of which C D is the radius, and A P is an arc. If the eye of the observer be placed at E, a reflected and erect image of the arrow M N will be seen at *m n*, but reduced in size. Of the numerous rays of light reflected from the surface of the mirror, only a few can enter the eye, and those which do, such as D E, F E, G E, and H E, are so reflected that the angles of incidence and reflection are equal. The ray M D is reflected in the direction D E, the angle of incidence M D N being equal to the angle of reflection N D E. The same is true of the rays M F, N H. By carrying back the rays E D, E F, they will be found to meet at the point *m*, and they will appear to an eye placed at E as if they had come from their focal point *m*. In the same way the rays E G, E H, will apparently issue from *n*, —all the points composing the image *m n* being foci conjugate to the points composing the object M N. The small image *m n* will therefore be the virtual image of M N. By drawing the lines M C, N C, it will also be found that the virtual image *m n* is always within those lines, hence the image is erect and always smaller than the object. It is important also to recollect that the size of the image *m n* is to the size of the object M N as the distance of the image from the centre of the mirror *m* C is to C M, the distance of the object. The image *m n* will recede from the surface of the mirror, as the object M N recedes from it, and when the object M N is indefinitely distant, as it often is in the case of objects placed before the cornea, the image *m n* will be situated about half-way between the mirror and C, that is at a point corresponding to half the radius of convexity. It follows also from this, that the greater the degree of convexity of the surface of the mirror, the smaller will be the virtual image, a fact which may be easily demonstrated by comparing the sizes of the reflected images in convex mirrors of different degrees of convexity.

Formula for calculating radius of curvature of cornea.—When we apply these principles to the cornea, we find that it acts as a convex mirror, having a virtual image behind it at a point situated at a distance of half the radius of its convexity. The size of the image must be measured, and from its size the radius of curvature may be calculated thus :



Let C D in the above Figure be the cornea, and E F H its optical axis. The object A B, placed before it will be reflected by its surface, so that its virtual image will be *a b*, placed at F, that is at a distance of half the radius E G. Draw the lines A *b*, B *b*. The object A B will be to the image *a b* as the distance H G is to G F, that is half the radius. Let R = the radius—

$$\mathrm{A\,B} : a\,b \; : : \; \mathrm{H\,G} : \mathrm{G\,F} \text{ (that is half R)}$$

$$\tfrac{1}{2}\,\mathrm{R} = \frac{\mathrm{H\,G} \times a\,b}{\mathrm{A\,B}}$$

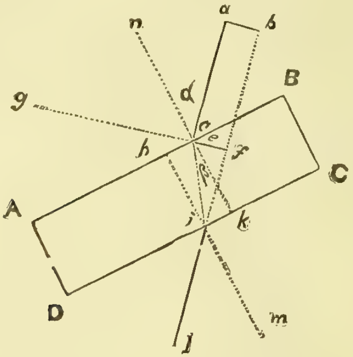
$$\text{Or } \mathrm{R} = 2\left(\frac{\mathrm{H\,G} \times a\,b}{\mathrm{A\,B}}\right)$$

Thus let A B = 1000 mm. ; *a b*, 1 mm. ; and H G, 3800 mm. ; what is the radius of curvature ?

$$\tfrac{1}{2}\,\mathrm{R} = \frac{3800 \times 1}{1000} = 3{\cdot}8$$

$$\mathrm{R} = 3{\cdot}8 \times 2 = 7{\cdot}6 \text{ mm.}$$

Optical principles of the ophthalmometer.—The instrument by means of which we measure the size of the reflected image on the convex surface of the cornea or lens is termed the Ophthalmometer (οφθαλμος, the eye ; μετϱον, a measure). This ingenious instrument was invented by Helmholtz. In order to understand its practical application, it is necessary, in the first instance, that we examine the optical principle on which it is constructed. When a ray of light falls perpendicularly on the surface of a glass plate, it passes through it without undergoing any refraction. If, however, the plate be held obliquely to the direction of the ray, as seen in the accompanying figure, we obtain a different result.



Here A B C D in the above figure represent a plate made of flint glass, having the ray $a\ c$ impinging upon its surface. It is refracted in the direction $c\ i$, and on passing again from the flint glass into the air, it is a second time refracted in the direction $i\ l$,—$i\ l$ being parallel with $a\ c$. Draw a line perpendicular to A B, namely $n\ c$, and continue it to k. The angle $a\ c\ n$ is equal to the angle $m\ i\ l$, being produced by parallel lines falling on parallel surfaces. The angle α bears a ratio to the angle β,—the angle of refraction. The index of refraction of flint glass is 1·6. Hence the sine of the angle $\alpha = 1{\cdot}6\ (\sin\ \beta)$. Consequently, if the eye be situated at l, the point a will not be seen at a, but at b, in the direction of the line $l\ f\ b$. The glass plate, therefore, effects a *displacement* of the point a to the right, and to an extent indicated by the length of the line $a\ b$. As yet we do not know the length of $a\ b$, but it may be represented by the line $c\ f$, which is equal to $a\ b$ by parallel lines. The line $c\ f$ we will term e. In the triangle $c\ f\ i$, $c\ f$ is opposite to the angle $c\ i\ f$, and $c\ i$ is the hypothenuse, therefore—

$$\frac{e}{c\ i} = \sin\ c\ i\ f.$$

and therefore

$$e = c\ i \cdot \sin\ c\ i\ f.$$

But e has not yet been measured, neither do we know the length of $c\ i$, nor the angle $c\ i\ f$. We must now find $c\ i$. This line is, as the figure shews, the hypothenuse of a triangle $c\ i\ k$; and one of the sides of this triangle, $c\ k$, is equal to the thickness of the glass plate, which we will term P. The line $c\ k$ is adjacent to the angle $c\ i\ k$, and hence we get

$$\frac{\mathrm{P}}{c\ i} = \cos\ \beta,$$

by multiplying $c\ i$, we have

$$\mathrm{P} = \cos\ \beta \cdot c\ i,$$

wherefore

$$c\ i = \frac{\mathrm{P}}{\cos\ \beta.}$$

Now we know that P equals the thickness of the glass plate, and that the sines of the angles α and β are in a known ratio. But by substituting the value of $c\ i$ in the previous equation, we have

$$e = \frac{\mathrm{P}}{\cos\ \beta} \sin\ c\ i\ f.$$

We see now that the $c\ i\ f$ equals $h\ i\ f - h\ i\ c$; but $h\ i\ f$ equals the angle of incidence α, in that their sides are parallel; and $h\ i\ c$ equals the angle of refraction β, because they are alternate angles. Therefore $c\ i\ f$ equals $\alpha - \beta$, and $\sin\ c\ i\ f = \sin\ (\alpha - \beta)$. We have therefore the following formula: (e representing the amount of displacement of the point a towards b and P the thickness of the plate).

$$e = \mathrm{P}\ \frac{\sin\ (\alpha - \beta)}{\cos\ \beta.}$$

But as there are two such plates in the ophthalmometer, we have the complete formula, in which E will equal the total displacement.

$$\mathrm{E} = 2\ \mathrm{P} \frac{\sin\ (\alpha - \beta)}{\cos\ \beta.}$$

The use of the ophthalmometer, therefore, is to supply us with the angle α, and as we know the thickness of the glass plates, and the index of refraction between air and flint glass (namely 1·65), by applying the above formula, the amount of lateral displacement may be ascertained. Suppose the thickness of the glass plate to be ·325 mm., the index of refraction 1·65, and the angle of incidence 6°, we find, by the use of logarithmic tables, that $\beta = 3° 37'$, very nearly. Therefore $\alpha - \beta = 6° - 3°$

$37' = 2° 23'$. This gives, on referring to the tables, $e = 0·027$ mm. very nearly.

Description of the ophthalmometer.—This instrument consists of a telescope suitable for short distances, part of which is seen in Plate XXI. fig. 24, *c*. In front of the telescope there is a square brass box, *a b b*, having the inner surface blackened. The box has a circular opening near *b b*, which is usually closed with a plate of very thin glass. In the interior of this box there are vertical plates of flint glass *b b*, fitted into frames, and moving the one at an angle with the other, by means of a rack and pinion movement, on a circular disc or wheel seen in Fig. 24, *c*, which is set in motion by turning the screws seen on the top and bottom of the box, the lower one being marked *d*. In Fig. 24, *f*, we see the inner surface of the bottom of the box with the circular wheel just alluded to. In connection with each pinion, and placed on the outside of the box, there are two circles made of steel, and carefully graduated into 360 degrees. These circles are upon the same axis as that on which the glass plates in the interior of the instrument revolve, the upper circle corresponding to the one plate, and the lower to the other plate. There is a fixed vernier at the point *a*, so that by observing the number of degrees on the circle opposite the zero of the vernier, we read off the number corresponding to the obliquity of the plate, or in other words, the number of degrees formed by the angle of incidence, namely, α. In making accurate observations, a number of readings should be taken on both graduated scales, and the differences between these readings should never exceed the one-tenth of a millimetre. If they do, the instrument is not in proper order, owing to the plates not moving at equal rates, or owing to a flaw in the glass.

Mode of using the ophthalmometer.—The first requisite for ophthalmometric observations, is a room having the walls blackened, and from which all sunlight can be excluded. The ophthalmometer is placed at a distance of ten feet from the eye under examination, and on a level with it. The object to be reflected on the cornea, until recently, was the distance between three candle flames placed beside the experimenter, two being on his right hand and one on his left. Helmholtz has, however, now substituted for this an apparatus consisting essentially of three small *rectangular mirrors* fixed by universal joints to a graduated wooden rod about four feet long. The distance between the mirrors may be regulated by sliding them in moveable sockets along the rod. In the centre of the rod there is a circular movement round a graduated scale, so that the rod may be placed vertically, obliquely, or horizontally, according as it may be desirable to obtain images in a vertical, oblique, or horizontal meridian of the cornea. This mirror-apparatus is screwed to a table immediately in front of the ophthalmometer. A candle flame is now placed on the right or left hand side of the eye to be examined (for the right eye on the right side and for the left eye on the left), as near it as possible, and on the same plane, a dark screen intervening, so as to protect the eye from the glare of light. The experimenter now throws, by means of the mirrors, a reflection of the light from each mirror upon the eye. He then directs his own eye to the telescope of the ophthalmometer, and by carefully focusing the instrument, and directing it to the eye under observation, he sees three minute specks of light, thus *   *   * on the cornea. The vernier of each scale of the ophthalmometer is now at zero. Then, by turning the screws already mentioned, the glass plates in the interior of the box are placed obliquely, and the motion is continued until six small specks of light are seen thus :—

*	*	*	*	*	*
1	*a*	2	*b*	3	*c*

Here the asterisks numbered 1, 2, 3, represent one-half of the amount of displacement in the one direction, and those marked *a*, *b*, and *c*, half the displacement in the other direction. Thus the three original images have been displaced through a distance equal to that between the two extreme images. The number of degrees through which the plates have moved are now read off, giving the angle of incidence, and by means of the calculation above described, the size of the image is ascertained. The following measurements are now made : First, the distance between the upper and lower reflecting mirrors—this gives the size of the object ; and second, by a tape line divided into millimetres, the distance from the anterior surface of the cornea to the centre of the apparatus bearing the mirrors ; but as these reflect rays of light from the candle flame, this measurement must be doubled. We now know the size of the object, the size of the image, and the distance of the object from the cornea ; and from these data, by the formula already given, the radius of curvature is easily calculated. (For an example, see p. 565.)

Donder's method of using the ophthalmometer.—This is an easier, though a less accurate, mode of measuring reflected images. It consists of preparing a scale, in which each degree, or fraction of a degree, corresponds to a certain size in millimetres. The mode of constructing it is as follows: Place a small white ivory scale, divided into tenths of a millimetre, at a distance of ten feet from the ophthalmometer. Turn the plates until the lines on the scale diverge and ultimately pass through any given distance, say $\frac{1}{10}$ of a millimeter, $\frac{1}{8}$, $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{4}$, or 1 millimeter. The number of degrees corresponding to each of these displacements is noted, and thus a scale, by numerous observations, may be readily constructed. Observations are to be made on the living eye as described. When the distance between two reflections on the cornea, representing the image, has been displaced through its whole extent, the number of degrees are noted, and on referring to the scale of measurements prepared as above, the size of the image is at once known.

Measurements made by means of the ophthalmometer.—We give here various measurements in millimetres made by means of the ophthalmometer, which are intended to serve as standards of comparison for students or others who may make a special study of, and devote time to, the subject :*

OPTICAL CONSTANTS.	Myopic eye. *Knapp.*		Hypermetropic eye. *Woinow.*		Presbyopic eye. *Adamück and Woinow.*	
	Rest.	Accom-moda'n.	Rest.	Accom-moda'n.	Rest.	Accom-moda'n.
Radius of cornea	7·2053	7·2053	8·00747	8·00747	7·15568	7·15568
Radius of anterior surface of lens	9·0641	5·0296	9·3785	5·2904	10·2021	8·5975
Radius of posterior surface of lens	6·4988	5·0855	6·2480	4·9714	6·2156	5·0001
Distance of anterior surface of lens from the cornea	3·4786	2·8432	3·6175	3·0028	3·23731	2·98985
Thickness of the lens	3·6225	4·2579	3·5825	4·1972	3·96269	4·21015
Focal distance of the lens	43·133	30·939	44·9616	31·185	46·357	38·1513
Index of refraction of the cornea, aqueous humour and vitreous humour	1·3465†	...	...	...	...	...
Index of refraction of the lens	1·4545†	...	...	...	...	...

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* M. Woinow, Ophthalmometrie, Wien. 1871.

† Helmholtz, Physiologische Optik.

The apparatus of Knapp for holding the head.[*]—This apparatus, designed by Professor Knapp, now of New York, is for the purpose of securely holding the head of the individual whose eye is being examined with the ophthalmometer. It is composed of a circular piece of wood placed vertically, which may be turned round on an axis, and which has holes cut for the nose, eyes, and mouth. The head is held steady by two flat pieces of wood, which are moved by screws so as to be applied, one to each side of the head. These are well padded.

The phakoscope of Helmholtz (φαϰη, the lens; σϰοπεω).—This is an irregularly triangular box, shaped somewhat like a stereoscope, made of wood or paste-board, and well blackened in the interior. It has four apertures, one for admitting the rays of light from a candle or lamp, another for the eye to be examined, and a third for the eye of the observer. The fourth opening is immediately in front of that for the eye to be examined, and is furnished with a sliding door bearing a small vertical needle. By causing the person whose eye is being examined to direct his attention to the needle, the eye is accommodated for near distances, but if the needle be removed by pushing down the little door, the eye may accommodate itself to any distant object. When an eye is examined in this manner three reflections are seen, one from the anterior surface of the cornea, Fig. 24^a 1, a second from the anterior surface of the lens, 2, and a third, which is inverted, from the posterior surface of the crystalline lens or anterior layer of the vitreous humour, 3. The relative positions of these images, when the eye is accommodated for distant objects, is seen in Plate XXI. fig. 24^a, while that represented in Fig. 24^b shews the position in which they are in an eye looking at a near object. It will be observed that in the latter, the anterior surface of the cornea has become more convex, because the image 2 in Fig. 24^b has advanced nearer to 1 than in Fig. 24^a. This is the most suitable instrument for demonstrating the accommodation of the eye to distance according to Cramer (see p. 342).

The ophthalmoscope.—This valuable instrument, also invented by Helmholtz, is for the purpose of illuminating the posterior chamber of the eye, so as to enable us to see the retina, the entrance of the optic nerve, &c. There are many varieties of ophthalmoscopes, which it is unnecessary to describe here; but they all consist essentially of a powerful mirror, having a small round hole in its centre, which is used for reflecting a beam of light into the eye under examination; and of a biconvex lens for the purpose of magnifying the retina, and of projecting an image of the latter forwards to a point somewhere between the eye of the demonstrator and the eye of the patient. The mode of using the instrument is as follows: Let the individual whose eye is to be examined, be seated in a dark room on a chair of a convenient height, and place a gas light, furnished with a ground-glass shade, or a moderator lamp, immediately behind his shoulder, and yet close to the side of his head. Let the light be on a level with the eye, and so far behind it that the countenance is in the shade. If this cannot be so arranged, place a dark shade between the eye and the light. The student is now to sit down opposite, take the mirror in his right hand and apply the back of it to his own eye, at a distance of about eighteen inches from the eye under examination, and looking carefully through the small hole in the back of the mirror, he so moves the latter as to catch the rays of the light from the lamp, and to reflect them into the patient's eye. He must now take the biconvex lens between the forefinger and thumb of the left hand, and hold it at a distance of about an inch in front of the patient's eye, keeping the hand steady by resting the little finger on the forehead of the patient. Then by a slight backward and forward movement of his head and the mirror, the student will succeed in catching the proper focal distance, and the image of the retina will then be distinctly seen.

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[*] Knapp, Archiv. v. Ophthalmol. Bd. VI. Ab. 2, and Archiv. f. Augen und Ohrenheilk, 1 Bd. 2 Ab.

In the axis of the eye-ball the *yellow spot* (*macula lutea*) may be seen forming a slight oval patch, and having in its centre a small bright dot, the *fovea centralis*, the thinnest part of retina. About the 1-10th of an inch to the inside of the yellow spot, we now observe a white or rose-coloured round spot, bounded by a well-defined border, and having radiating from its centre a number of minute vessels. This is the entrance of the optic nerve, and the vessels are branches of the central artery of the retina. It is sometimes termed the optic disc (*porus opticus*), and it has also been called the optic papilla, because at this place the nervous substance of the retina is slightly elevated, so as to form an eminence (*colliculus nervi optici*). The neighbourhood of the optic disc and yellow spot is usually of an orange-red colour, and is richly supplied with branches of the retinal vessels. The yellow spot is seen most distinctly when the individual looks straight forward, and the optic disc is demonstrated when the eye is rolled a little inwards. By causing the patient to move his eye in different directions, the whole surface of the retina may be examined.

EXPERIMENTS ON HEARING.

This department of practical physiology has become, chiefly owing to the brilliant researches of Helmholtz, one of the most inviting fields of study. Before entering upon it, however, the student should be familiar with the general principles of acoustics explained at pp. 129, 134. The following are a few examples of the kind of apparatus used, and the experiments performed.

Helmholtz's model for explaining the mechanism of the bones of the ear.—This is a model of the tympanum, having accurate models of the *malleus*, *incus*, and *stapes*, moving upon each other by joints, and having attached to them, at the proper points, cords which run in the direction of, and represent the muscles of, the tympanum, viz., the *tensor tympani*, *laxator tympani*, and *stapedius*. By tightening or relaxing these cords, the action of the chain of bones or the *membrana tympani*, on the one hand, and on the membrane covering the *fenestra ovalis*, on the other, may be easily demonstrated. It may also be shewn by means of this apparatus how the vibrations of the air communicated to the *membrana tympani* are carried onward through the chain of small bones to the *fenestra ovalis*.

Monochord of Helmholtz.—This is an apparatus consisting of a long narrow box, on the upper surface of the lid of which there is a cord drawn tightly over two ivory bridges, placed one at each end of the box. There is also a bridge, of the shape of that of a violin, which may be moved in any direction beneath the cord; and thus it may be shewn that vibrating cords of different lengths produce various musical notes. Attached to the instrument there is a trumpet-shaped resonating apparatus, having the wide end covered with a delicate membrane. This part of the apparatus may be moved along the side of the box, so as to be opposite to any given point of the vibrating cord, and the note corresponding to the vibrations will be distinctly heard.

The apparatus of Appunn for illustrating the researches of Helmholtz, adapted for physiological purposes.—This is an apparatus invented and made by Georg Appunn, of Hanau, near Frankfort-on-the-Maine.* It consists of a strong table provided with a bellows and air-chest. The entrance of air from the bellows into the chest is regulated by a valve, which may be opened or shut at pleasure. On the top of the table there are six square holes communicating with the air-chest, each being provided with a sliding valve, which can be opened or shut by a rod attached to it. These square holes serve as sockets, into which we can fit the different parts of the apparatus. When we wish to use any particular instrument, the valve beneath it is opened, and thus air is at once admitted into it from the air-chest.

The following are the principal parts of the apparatus :—

1. *An over-tone apparatus.*—This part of the instrument consists of a rectangular chest, having in its interior sixty-four metallic tongues, placed transversely, and carefully constructed, so that the vibration of each produces a certain musical tone. Suppose we were to divide a vibrating cord into equal parts of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, and so on up to the 1-64th of its length, we would obtain the tones of this apparatus. Underneath each tongue there is a sliding stop, which has a short metallic rod attached to it. The end of each rod is finished with a small knob, by pulling out which, the sliding valve under any particular tongue may be withdrawn, and the corresponding musical tone produced by working the bellows. In order to maintain the sound while the bellows is refilling, the top of the box of the over-tone apparatus moves upwards and downwards like an accordion, and the tongues vibrate whether the air passes from below upwards, or from above downwards. By means of this apparatus, as we can sound several notes at the same moment, the peculiar colour, or timbre, or, according to Helmholtz the *klang* of a musical note may be demonstrated. Every musical note contains not only its fundamental tone, and overtones, but also other tones called the octave, the duo-decimo, double octave, &c., the ratio of the vibrations of which are as 1 : 2 : 3 : 4 : 5 : 6 : 7, and so on. In order to detect these over-

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* Ueber die Helmholtz' sche Lehre von den Tonempfindungen, &c.

tones, we require a series of instruments termed *resonators.* These are globes or cones made of copper or tin, and each one is so constructed that the air in its interior is thrown into vibration by one of the over-tones in the musical note. With Appunn's apparatus, twenty-nine of these resonators are supplied. They vary in length from 4½ feet to 3 inches, and they are all conical and made of tin. The narrow end is placed close to the ear, and the base directed upwards, and if possible the observation should be made at a distance from the place or instrument from which the sound issues. The presence of over-tones in a musical note may be shewn by sounding the fundamental tone. Then, by withdrawing the stops corresponding to the different over-tones of that particular note, we find that its colour or quality depends on the different number and relation of the over-tones. It is this fact which explains why the same note on a flute, a clarionet, a piano, or a trumpet, differ from each other in quality. The fundamental tone is the same in each, but the number and relation of the over-tones vary. The soft note of a flute contains fewer over-tones than the same note sounded on a trumpet. For instance, if we sound on the over-tone apparatus the notes in the proportions 1 : 2 : 3 : 4 : 5 : 6 : 7, &c., which are the over-tones of the fundamental tone = 1, the sound becomes stronger and rougher as we proceed. This illustrates the law laid down by Helmholtz, that "The more over-tones a compound note contains, the rougher is its quality or timbre." The quality of the voice in different individuals depends on the number and strength of these over-tones.

Another method of observing the over-tones is to sound the fundamental note on the over-tone apparatus, and the students may hear distinctly the various over-tones corresponding to the particular note by listening with the resonators at the other end of the room. In order to sound the fundamental note with volume and intensity, so that the over-tones may be detected in a room with a large audience, Appunn's apparatus is provided with two powerful *tongue-pipes.* These consist of rectangular wooden pipes, having at the top a wedge-shaped box, the apex of the wedge pointing downwards, and furnished with a vibrating metallic tongue. A large cone made of tin is fitted, apex downwards, into the top of the pipe. This acts as a powerful resonator, and the note produced by the metallic tongue is increased in intensity.

After some practice with this instrument, one can detect the over-tones even without the resonators. The resonators do not produce the over-tones, but the confined mass of air within them, by its vibrations in unison with those causing the over-tones, strengthens the latter, and renders them appreciable to the human ear. The over-tones are not therefore formed in the ear, as was supposed before the researches of Helmholtz, but they are produced in the air surrounding the apparatus causing the fundamental note.

The production of combination tones.—If, by the over-tone apparatus, we sound two notes of different pitch at the same time, and if they correspond in strength, we may hear, by using a resonator, not only the two primary notes, but a third, which is deeper than the primary. This is termed the combination or ground-tone, first discovered by Andreas Sorge in 1740, and investigated by a violinist, Tartini, and often called after the latter, *Tartinian tones.* For instance, if we sound two notes on the over-tone apparatus, the proportion of whose vibrations are as 2 : 3, or 3 : 4, or 4 : 5, or 6 : 7, or 7 : 8, we hear the ground tone, which is always, in this case, the tone whose vibrations are as $1 = C_2$. The student, until his ear is accustomed to the apparatus, should sound the notes 16 : 20, or 20 : 24, or 24 : 28, and he will easily hear the deep ground tone, the vibrations of which will stand in the arithmetical ratio of 4 to the figures just given. In the same way the proportions 16 : 18 : 20 : 22 : 24 produce a ground-tone = 2; those of 15 : 18 : 21 : 24 : 27 produce tone = 3; and so on.

The production of difference tones.—The difference tone is that in which the number of its vibrations are equal to the difference between those of the two primary tones. For example, suppose we sound on the over-tone apparatus two notes, the ratio of whose vibrations are as 16 : 20. The difference tone will have a vibration of 4, that is, $20 - 16 = 4$. But the vibrations of 1 (the lowest in the over-tone apparatus) = 32 in the second. Therefore, the vibrations of 16 will be $16 \times 32 = 512$; of 20 will be $20 \times 32 = 640$; and of the difference tone will be $4 \times 32 = 128$ vibrations in an equal period of time. This tone was first discovered by Helmholtz.

The production of summation tones.—When we sound two tones of unequal pitch, but the ratio of the vibrations being as 16 : 18 : 20 : 22 : 24, &c., we obtain not only, as already described, a fundamental or ground tone, and a difference tone, but we also produce a third called a summation tone. For example, if we sound on the over-tone apparatus the tones 4 : 6, we hear, by means of resonator No. 10, another tone, the vibrations of which are in the proportion of 10 : 4 : 6. We hear in those circumstances a musical chord, thus (*e* = summation tone) :

C : G : *e*
4 : 6 : 10

And in the same way by sounding 1 : 2, 2 : 3, 3 : 4, or 4 : 5, we may produce the corresponding summation tones, 3, 5, 7, 9, &c. ; and these summation tones may be heard with resonators 3, 5, 7, 9, &c.

By this apparatus also, even higher tones may be obtained. Thus, when we sound 2 : 3, we may hear the deep difference tone = 1 ; at the same time the summation tone 2 + 3 = 5 ; and with care, by increased attention, we may hear another tone, the ratios of whose vibrations are as 2 × 2 + 3 = 7 ; and even a third, namely, that produced by 2 × 2 + 2 × 3 = 10. Thus, when we sound 2 : 3, and provide four individuals with the resonators marked 1, 5, 7, and 10, each will hear distinctly the tone corresponding to the resonator he employs.

2. *An apparatus to demonstrate deep difference tones.*—This consists of two tall organ pipes placed at the end of the table, and communicating with the air chest. These pipes are of equal length, but each is furnished with a stop attached to a vertical rod, by which the length of the vibrating column of air in the one may be made to differ from that in the other. When the stops are so arranged that the columns of air in the two pipes are equal, and the bellows are worked, we obtain two notes so perfectly in unison as to be undistinguishable. If, however, the length of one of the columns of air be diminished by pushing down the stop, the rate of vibration is changed in that pipe, and we hear two notes or impulses alternating with each other ; a kind of shake. It may also be shewn that these impulses increase in rapidity as we augment the difference between the lengths of the columns of air in the two pipes, that is as the vibrations in the two differ. And it may be demonstrated that the number of impulses per second is always equal to the difference between the rates of vibration.

3. *A Vocal apparatus.*—This will be described with the experiments on voice (see p. 579).

4. *Appunn's tone-measurer.*—This consists of an apparatus similar in structure and appearance to the over-tone apparatus already described. It contains thirty-three tones, marked 0, 1, 2, 3, 4, 5, &c., on to 32; and these tones are so arranged that the difference between the vibrations of any adjacent two, such as 0 : 1, or 1 : 2, or 2 : 3, and so on, produce, when sounded together, exactly *four* impulses per second. In the same way when 0 : 2, or 1 : 3, or 2 : 4 are sounded, we have eight impulses per second; again 0 : 3, or 1 : 4, or 2 : 5 give sixteen impulses per second, and so on. With this instrument we can readily determine the number of vibrations in any given tone (see p. 347).

Experiments on Voice.

The human voice is produced by the vibrations of the true vocal cords (p. 351). This may be illustrated in several ways.

1. *By Müller's artificial larynx.*—This consists of a wooden tube of the form seen in Plate XXI. fig. 25, *f*, having at *e* a brass frame-work for holding a piece of india-rubber tube, and moving on a hinge, so that the margins of the latter may be separated or approximated, or relaxed or rendered tense. On blowing through the end of the tube, various sounds are produced according to the degree of tension of the india-rubber margins. It may be shewn that as we increase the tension of these, the pitch of the sound rises, while it is lowered when we remove the tension.

2. *By Müller's apparatus for experimenting on the vocal cords themselves.*—A view of the principal portion of this apparatus is seen in Plate XXI. fig. 25. It consists of a broad wooden stand, having two or three strong uprights, provided with numerous holes and screws, by which the larynx may be attached. In Fig. 25, the anterior part of a human head, with the larynx left attached to it, is affixed to the apparatus. Into the trachea there is inserted and securely fastened the bent wooden tube *f*, by which air can be forcibly blown upwards through the glottis. When this is done, a sound is produced, which may be increased in pitch in two ways: 1st, by means of the rectangular forceps *a*, movable on the steel rod *b*, which grasp the larynx and thus approximate the cords; or 2nd, by fixing a small hook into the anterior and upper border of the thyroid cartilage, and

carrying a thread from this hook over the pulley *c*. By placing weights in the scale or cup *b d* attached to the thread, the thyroid cartilage is pulled forwards and the cords tightened.

Instead of using part of a head, as shewn in Fig. 25, it is more satisfactory to make a special preparation of a larnyx, by removing it from the neck, clearing it from the muscles, and by cutting off the upper part down to the level of the true vocal cords. It may then be clearly demonstrated that voice is produced by the vibrations of these cords, and numerous experiments may be performed, shewing how they are influenced by the various muscles, and the change of note consequent thereon.

Formation of vowel sounds.—These may be illustrated by the special apparatus made by Appunn, already alluded to. It consists of a combination of wooden organ pipes, having stops so that air may be admitted into one or more at pleasure. It may be shewn that the vowel *a* consists of a fundamental note and of certain over-tones; the vowel *e* of a fundamental note and other over-tones, and so on. The fundamental note is produced by the vibrations of the cords, and is the same for all the vowels; but the over-tones are produced in the upper part of the larnyx, and are modified by the resonance of the mouth. It is well known that the vowels, if sounded by different voices, have not the same quality or timbre; a fact due partly to the over-tones varying in different individuals, and partly to the effect of resonance of the oral cavity, which also varies in shape. (See p. 353.)

3. *The Laryngoscope.*—The idea of illuminating and rendering the larynx visible by means of a reflector, has been more or less attempted by Liston, Warden, Avery, Garcia, and others, but abandoned as impracticable in medicine, until successfully revived in recent times (1858–59) by Professor Czermak. For the examination of the larynx he employs, 1st, a perforated mirror, by means of which a powerful light is thrown from a lamp into the back of the mouth, and through which the operator gazes in the direct axis of the illuminating rays. This mirror may be attached to a bent stalk, the end of which can be held firmly by the teeth, but it is far more conveniently, for purposes of demonstration, held firmly in the left hand. 2d, A laryngeal mirror of glass or steel, varying in size, attached to a stem at one of its corners, which having been previously warmed to pre-

vent condensation of the breath upon it, is placed in front of the uvula, and reflects the image of the rima glottidis to the eye of the observer.

The person examined should place his hands upon his knees, the upper part of the body is advanced forwards, the neck bent onwards, the nape slightly inclined backwards, the mouth widely open, the tongue flattened and held a little without. The observer is seated in front of the person to be examined ; he places in his mouth the handle which supports the illuminating mirror, and looks through the central opening ; the laryngeal mirror, introduced into the back part of the mouth with the right hand, is illuminated by the light which is projected from the illuminating mirror. In the first place, the illumination of the back part of the mouth and the mutual position are regulated ; then the laryngoscope is heated, and its temperature regulated by the touch. After these preliminaries are gone through, the patient should open the mouth wide, and alternately inspire and expire deeply. While doing so, the laryngoscope is placed against the uvula and the *velum palati*, to sustain these parts a little, and the mirror is given a convenient inclination; at times it is impossible to avoid touching the posterior wall of the pharynx ; the examination is directed by the image we thus obtain. On telling the patient to pronounce ah ! the movement of the vocal cords is seen. Practice and reflection will bring each observer to comprehend the modifications to which he ought to submit this proceeding, according to the special circumstance ; whether, for instance, he has in some degree to advance or to withdraw the laryngoscope, to bend it, to lower or to elevate it, to change the position and attitude of the individual undergoing examination, raise his chair.

For the performance of many experiments, more especially those on the nervous centres and individual nerves, anatomical knowledge and operative skill are required. To these we have not specially alluded, neither do we profess to have exhausted those for which particular instruments have been invented ; but enough has been said to illustrate this department of physiology, and to assist the student in making himself familiar, practically, with the use of the extensive apparatus he will find in the laboratory.

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ERRATA.

Page 199, line 5 from top, *for* " action," *read* section.
,, 200, ,, 16 from top, *for* " are," *read* is.
,, 202, ,, 9 from top, *omit* " of Peyer and."
,, 215, ,, 2 from bottom, *for* " Poissieulle," *read* Poisseuille.
,, 216, ,, 19 from top, *for* " is increased," *read* are increased.
,, 219, ,, 17 from top, *for* " Hæmadrometer," *read* Hæmadromometer.
,, 224, ,, 9 from top, *for* " possess," *read* possesses.
,, 224, ,, 2 from bottom, *for* Plate IX.," *read* Plate XI.
,, 227, ,, 16 from top, *for* " by," *read* of.
,, 233, ,, 12 from top, *for* " selenurretted," *read* seleniuretted.
,, 234, ,, 11 from top, *for* " function," *read* functions.
,, 240, ,, 4 from top, *for* " some," *read* same.
,, 241, ,, 17 from bottom, *for* " liquid," *read* liquids.
,, 242, ,, 3 from top, after " these," *introduce* latter.
,, 247, ,, 3 from bottom, *for* " Helmholz," *read* Helmholtz.
,, 249, ,, 21 from top, *for* " contain," *read* contains.
,, 255, ,, 10 and 12 from top, *for* " kilos," *read* grammes.
,, 255, ,, 5 from bottom, *for* " shew," *read* shews.
,, 256, ,, 22 from top, *for* " corticle," *read* cortical.
,, 256, ,, 8 from bottom, *for* " uretors," *read* ureters.
,, 258, ,, 8 from bottom, *for* " 32," read 62.
,, 260, ,, 7 from bottom, *for* " anasarea," *read* anasarca.
,, 262, ,, 9, 12, and 13 from bottom, *for* " divided," *read* derived.
,, 263, ,, 6 from bottom, *for* " chorium," *read* corium.
,, 273, ,, 7 from top, *for* " absorption or decomposition," *read* decomposition and absorption.
,, 273, ,, 2 from bottom, *for* " undergo," *read* undergoes.
,, 274, ,, 4 from bottom, *for* " seven," *read* fifteen.
,, 276, ,, 6 from top, after " to," *introduce* help to.
,, 318, ,, 16 from bottom, after " convulsed," *introduce* and the eye is turned outwards.
,, 318, ,, 14 from bottom, *for* " outwards," *read* inwards.
,, 329, ,, 9 from bottom, *for* " Eckar," *read* Ecker.
,, 338, ,, 13 from top, *for* " opthalmotrope," *read* ophthalmotrope.
,, 342, ,, 11 from bottom, *for* " opthalmometer," *read* ophthalmometer.
,, 344, ,, 22 from bottom, *for* " right," read left.
,, 352, ,, 10 from top, *for* " differ," *read* differs.
,, 352, ,, 8 from bottom, *for* " precision to," *read* precision from.
,, 360, ,, 4 from top, *for* " contain," read contains.
,, 361, ,, 4 from bottom, *for* " preversions," *read* perversions.
,, 371, should be 369.
,, 380, line 13 from bottom, *for* " (Fig. 3, *h* to *k*)," *read* (Fig. 3, *m n o*).
,, 380, ,, 10 from bottom, *for* " (Fig. 3, *m* to *r*), *read* (Fig 3, *p q* and *h* to *k*).
,, 387, ,, 2 from top, *for* " vertebræ," *read* vertebra.
,, 389, ,, 8 from bottom, after " circle" *omit* the.
,, 390, ,, 10 from top, *for* " cerebral," *read* central.
,, 394, ,, 17 from bottom, *for* " mesteric," *read* mesenteric.
,, 395, ,, 9 from top, after " passing," *introduce* from.
,, 395, ,, 14 from bottom, *for* " thryroid," *read* thyroid.
,, 403, ,, 16 from bottom, *for* " tasselated," *read* tesselated.
,, 452, ,, 9 and 10 from top, *for* " Guiacum," *read* Guaiacum.
,, 501, ,, 16 from bottom, *for* " acromatic," *read* achromatic.
,, 549, ,, from top, Greek character is inverted.

ERRATA.

Page 2, line 13 from bottom, *for* "C_2 N," *read* C N.
,, 6, ,, 18 from top, *for* " of the above series," *read* of the first of the above series.
,, 6, ,, 11 from bottom, *omit* "free."
,, 10, ,, 4 from bottom, *for* "Ptalyin," *read* Ptyalin.
,, 14, ,, 15 from top, in formula for urea, *for* "O_2," *read* O.
,, 16, ,, 1 at top, in formula for xanthin, *for* "O," *read* O_2.
,, 16, ,, 16 from bottom, in formula for cholic acid, *for* "H_{49}," *read* H_{40}.
,, 28, ,, 3 from top, *for* "latter," *read* former.
,, 28, ,, 13 from bottom, *for* "Ca Fl," *read* Ca F_2.
,, 29, ,, 10 from bottom, *for* "possible," *read* impossible.
,, 37, ,, 17 from bottom, *for* "rises," *read* rise.
,, 38, ,, 9 from top, *for* "all," *read* cell.
,, 63, ,, 2 from top, *for* "but no fats," *read* and phosphuretted fats.
,, 63, ,, 5 from top, *for* "renders," *read* render.
,, 64, ,, 6 from bottom, *for* "some," *read* semi.
,, 74, ,, 1 at top, *for* "consists," *read* consist.
,, 77, ,, 14 from top, *omit* "a," and *for* "body," *read* bodies.
,, 80, ,, 21 from bottom, *for* "have" and "exist," *read* has and exists.
,, 81, ,, 21 from top, *omit* "basic."
,, 83, ,, 7 from bottom, *for* "commences," *read* commence.
,, 90, ,, 4 from top, *for* "consists," *read* consist.
,, 112, ,, 19 from bottom, *for* "straight," *read* straight or curved.
,, 121, ,, 14 from top, after "gas," *introduce* at zero C.
,, 125, ,, 9 from bottom, after "volume," *introduce* at zero C.
,, 131, ,, 1 at bottom, *for* 27, 27, *read* 24, 27.
,, 138, ,, 15 from bottom, *for* "Fraunhofer," *read* Frauenhofer.
,, 146, ,, 14 from bottom, *for* "magnetic," *read* diamagnetic.
,, 147, ,, 2 from top, *for* "inherent," *read* not inherent; and *for* "and evolved from them," *read* but developed in them.
,, 147, ,, 10 from top, after "is," *introduce* in.
,, 147, ,, 25 from top, *for* "intervals," *read* interval.
,, 152, ,, 10 from bottom, *for* "Zn SO_4," *read* Cu SO_4.
,, 155. ,, 15 from bottom, *for* "form," *read* kind.
,, 158, ,, 8 from top, *for* "was," *read* were.
,, 164, ,, 17 from bottom, *for* "fig. 24," *read* fig. 34.
,, 172, ,, 23 from top, *for* "opened," *read* closed.
,, 172, ,, 24 from top, *for* "closed," *read* opened.
,, 172, ,, 7 from bottom, *for* "clos." *read* open.
,, 175, ,, 17 from top, before "nerve," *introduce* the.
,, 178, ,, 3 from bottom, *for* "are," *read* is.
,, 179, ,, 17 from bottom, *for* "sensations," *read* secretions.
,, 182, ,, 7 from bottom, *omit* "gravity."
,, 183, ,, 15 from top, *for* "his," *read* its.
,, 185, ,, 17 from bottom, *for* "produce," *read* produces.
,, 186, , 12 from top, after "which," *introduce* its.
,, 190, ,, 17 from bottom, *for* "consists," *read* consist.
,, 193, ,, 1 at top, *for* "latter," *read* former.
,, 193, ,, 2 from top, *for* "former," *read* latter.
,, 194, ,, 13 from top, *for* "is," *read* are.

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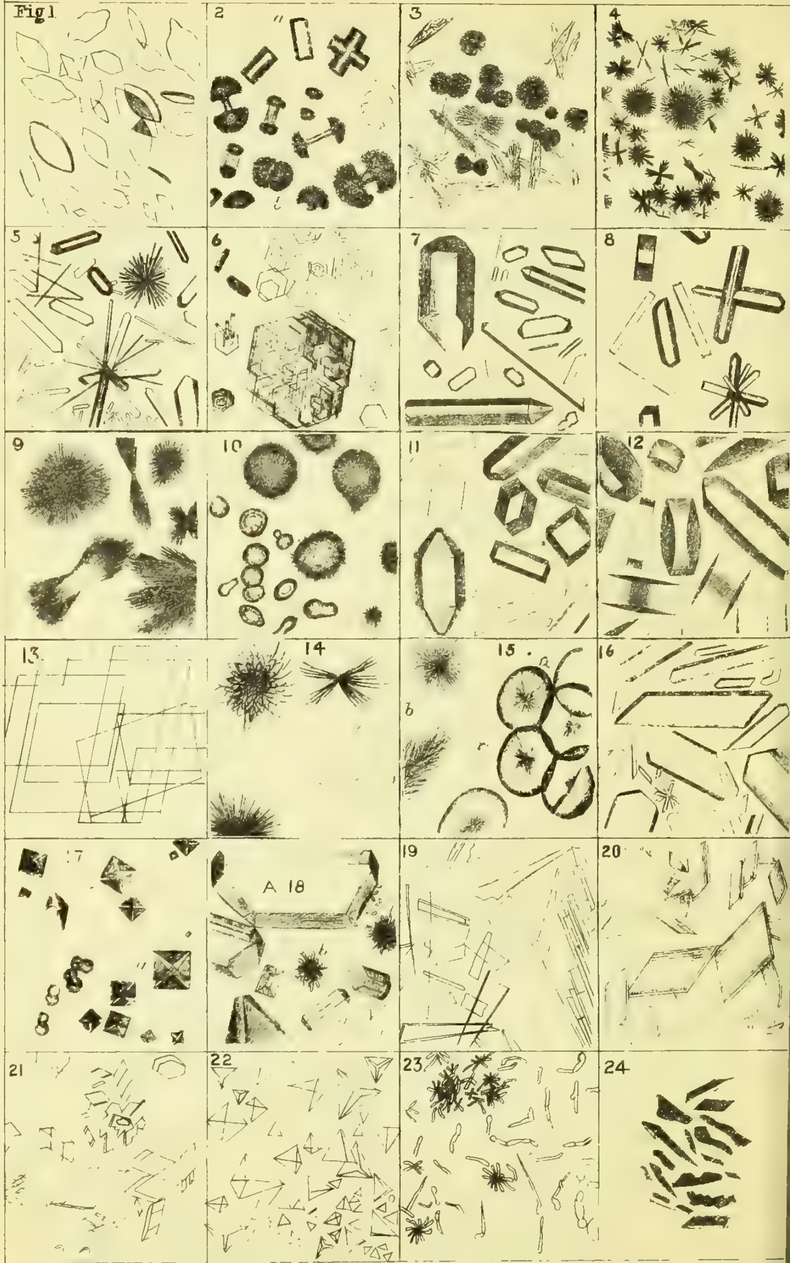
CRYSTALS. Plate I



Description of Plate I.—Crystals.

Fig. 1. *Uric acid.* Lozenge-shaped crystals with obtuse angles rounded off (pp. 13, 14).

Fig. 2. *Uric acid.* Dumb-bell crystals, and rectangular plates (pp. 13, 14).

Fig. 3. *Urate of Soda.* Acicular crystals forming round masses. Seen in various stages of aggregation (p. 14).

Fig. 4. *Urate of Ammonia.* Acicular crystals forming round masses. Seen in various stages of aggregation (p. 14). See also Fig. 18. *b*.

Fig. 5. *Hippuric acid.* Colourless prisms (p. 15).

Fig. 6. *Cystin.* Six sided plates (p. 16).

Fig. 7. *Taurin.* Six sided prisms terminating in four or six sided pyramids (p. 16.)

Fig. 8. *Allantoin.* Shining colourless prisms (p. 16).

Fig. 9. *Tyrosin.* Stellate groups of long silky needles (p. 17).

Fig. 10. *Leucin.* Balls, composed of scales or needles. Usually of a yellowish colour (p. 17).

Fig. 11. *Creatin.* Clear prisms, with pyramidal ends (p. 18.)

Fig. 12. *Creatinin.* Prisms with rounded ends (p. 18).

Fig. 13. *Cholestrin.* Soft nacreous laminæ (p. 19).

Fig. 14. *Stearin.* Soft nacreous laminæ or needles (p. 20).

Fig. 15. *Margarin.* *a*. Fat cells containing star shaped masses of needles; *b*. Star-like cluster of needles (p. 20).

Fig. 16. *Inosite.* Oblique prisms and tabular plates (p. 27).

Fig. 17. *Oxalate of Lime.* *a*. Octahedral crystals; *b*. Dumb bells (p. 23).

Fig. 18. *Triple phosphate of Ammonia and Magnesia.* A. Large crystal of triple phosphate; *a*. knife-rest crystal of triple phosphate; *b*. amorphous mass of urate of Ammonia; *c*. Clift form of crystal of triple phosphate (p. 29).

Fig. 19. *Hæmatin.* Rectangular plates (p. 32).

Fig. 20. *Hæmatocrystallin* or *Hæmoglobin.* Lozenge shaped crystals, colour dark red (p. 31).

Fig. 21. *Hæmatoidine.* Lozenge shaped thick crystals. This figure shews only the form; they are of a dark red colour (p. 31).

Fig. 22. Triangular blood crystals from a guinea-pig. This figure shews only the form. They are reddish coloured crystals (p. 31).

Fig. 23. Filamentous colouring matter of the bile (p. 32).

Fig. 24. Melanin (p. 31).

MOLECULAR ELEMENTS

Plate II

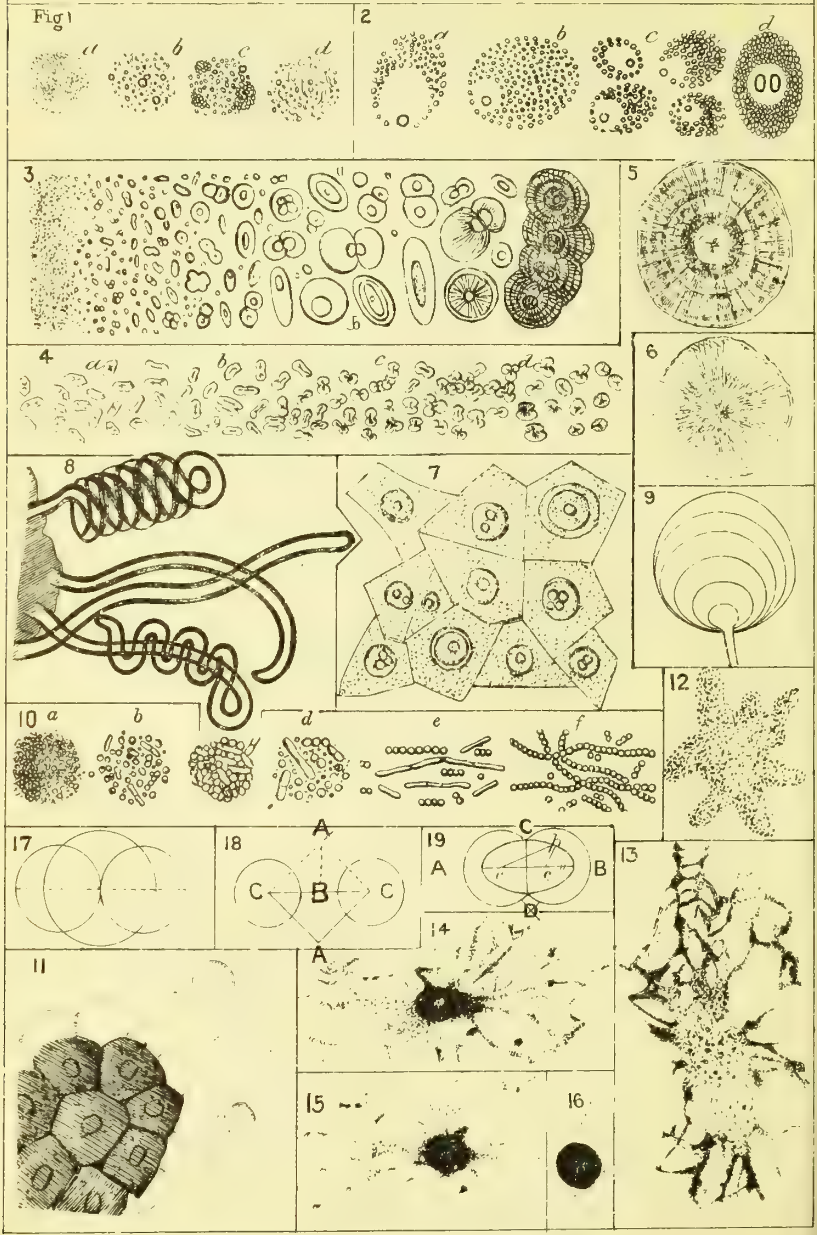


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Plate II.—Molecular Elements of the Tissues.

Fig. 1. *Various arrangements of Molecules.* *a.* Finely molecular mass ; *b.* Molecules varying in size as seen in milk ; *c.* Molecules aggregated in groups ; *d.* Histolytic molecules from broken down fibrous tissue (pp. 36, 37).

Fig. 2. *Fatty Molecules* precipitated from an alcoholic solution, and presenting the various forms here figured, shewing nucleolus, nucleus, and cell-mass, *a, b, c,—d* shews two nuclei (p. 38).

Fig. 3. *Precipitation of Carbonate of Lime,* from a viscous solution on a slide of glass, exhibiting molecular, nuclear, and cell forms in various stages of development. *a.* Oval body containing nucleus ; *b.* round body containing nucleus (p. 37).

Fig. 4. The *crystalline* passing into the *cell form,* the former from a limpid and the latter from a viscous fluid : *a.* crystalline form ; *b.* angles of crystals rounded off ; *c.* ovoid cell forms ; *d.* cell forms aggregated together (p. 37).

Fig. 5. A perfectly formed globular crystal of *Carbonate of Lime,* with radiating lines (p. 42).

Fig. 6. A similar crystal disintegrating (p. 43).

Fig. 7. Flattened crystals of *Carbonate of Lime,* adhering at their edges, from the surface of lime water, resembling epithelium in form (p. 44).

Fig. 8. *Protagon.* Processes shooting out from a mass of protagon on the addition of water, straight, curved, and spiral (p. 45).

Fig. 9. *Protagon.* Occasional concentric layers formed at the extremity of these protagon processes (p. 45).

Fig. 10. *Development of bacteria and vibrios on the surface of an infusion.* *a.* Molecular or proligerous mass ; *b.* larger molecules, with their union together to form short *bacteria* ; *c.* still larger molecules and bacteria ; *d.* the same more separated ; *e.* aggregation of molecules lengthways or melting together of bacteria to form *vibrios* ; *f.* chain-like molecular filaments—*Leptothrix* (pp. 46, 47, 48).

Fig. 11. *Globular diaphanous bodies,* caused by pressing epithelial cells in a viscous dropsical fluid (p. 44).

Fig. 12. An *Amœba,* a contractile molecular mass (p. 47).

Figs. 13, 14, 15, 16. *Vital movements of pigment Molecules.* Effects of diffusion and concentration of molecules in pigment cells in the skin of a frog (pp. 39–40).

Figs. 17, 18, 19. Diagrams explanatory of *Molecular Coalescence* (pp. 41, 42).

CELL ELEMENTS

Plate III

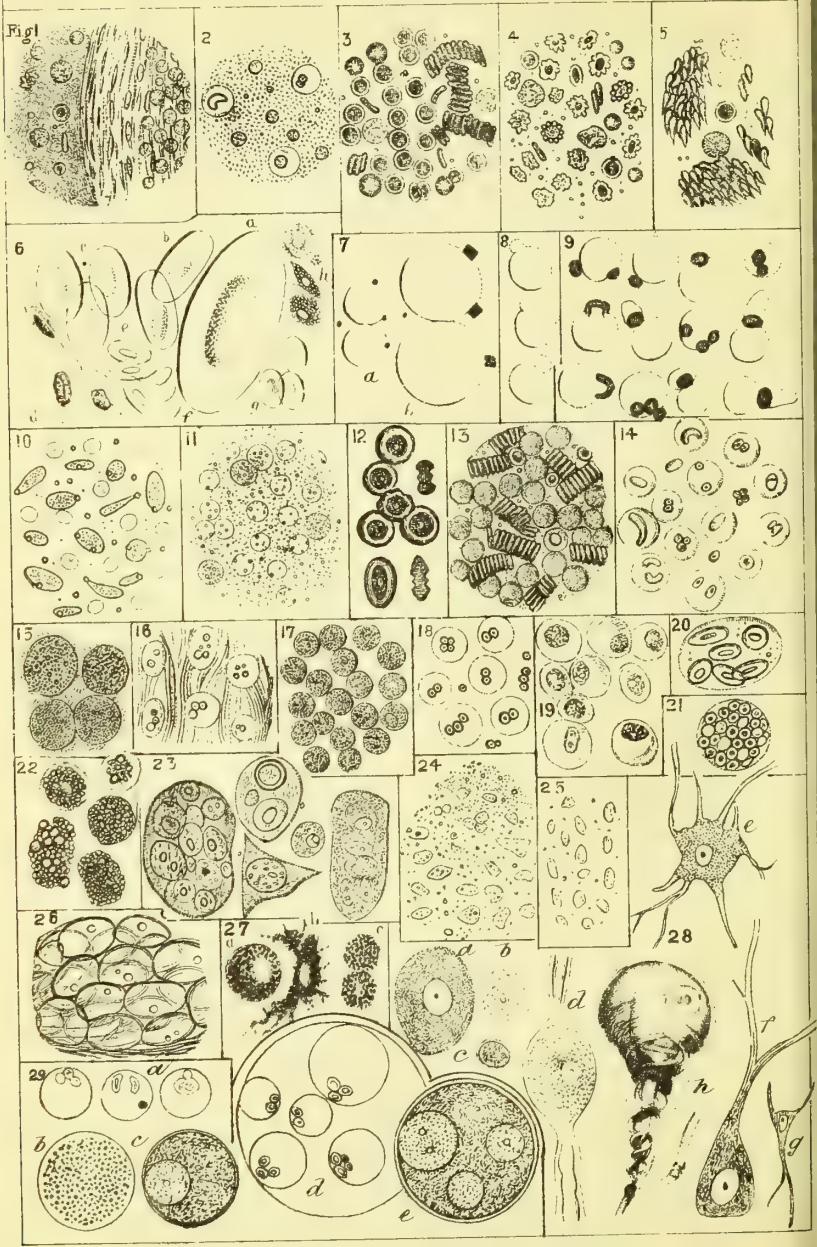

Plate III.—Cell Elements of the Tissues.

Fig. 1. *Chyle.* A drop of fresh chyle, partly coagulated. On the left of the figure, the corpuscles, some resembling in form coloured corpuscles of blood, the true chyle corpuscles ; others those of the colourless, or lymph corpuscles. They float in a finely molecular fluid, the molecular basis of the chyle. On the right of the figure, the fibrillated coagulum, with the corpuscles entangled in it. These are globular in the centre of the coagulum, but flattened and fusiform-shaped towards the margin (p. 60).

Fig. 2. *Chyle.* Effect of acetic acid on the fluid chyle ; chyle corpuscles rendered smaller and more opaque with thickened margins. The *lymph corpuscles* more transparent, with distinct nuclei (p. 60).

Fig. 3. *Blood.* Fresh human blood corpuscles. On the left of the figure, isolated ; on the right, aggregated in the form of *rouleaux* (p. 61).

Fig. 4. *Blood.* Altered forms of human blood corpuscles, caused by slight evaporation of the fluid, or from adding dense and viscous solutions (p. 63).

Fig. 5. *Blood.* Altered form and mode of aggregation of blood corpuscles when the blood is loaded with fibrin. See also Plate IV. fig. 2 (p. 63).

Fig. 6. *Blood.* Blood corpuscles from different animals. *a.* From proteus ; *b.* salamander ; *c.* frog ; *d.* the same after the addition of acetic acid ; *e.* bird ; *f.* camelidae ; *g.* fish ; and, *h.* crab (p. 61).

Fig. 7. *Blood.* Appearance of human blood after the addition of magenta (chloride of Rosaniline). *a.* (600 diameters) ; *b.* the same (2000 diameters), shewing that the dark molecules on the circumference are crystals (p. 63).

Fig. 8. *Blood.* Human blood corpuscles, after addition of solution of tannic acid (p. 63).

Fig. 9. The same, followed by addition of tincture of iodine (600 diameters) (p. 63).

Fig. 10. *Blood.* Human blood corpuscles from a case of cholera (p. 63).

Fig. 11. *Blood.* Human blood corpuscles disintegrating, from the fluid of a hæmatocele (p. 63).

Fig. 12. *Blood.* Blood corpuscles seen by direct light. The upper group are human, and the lower those of the frog (p. 61).

Fig. 13. *Blood.* Blood corpuscles in leucocythæmia (p. 64).

Fig. 14. The same after the addition of acetic acid (p. 64).

Fig. 15. *Mucus.* Mucous corpuscles, from the fauces.

Fig. 16. *Mucus.* The same after the addition of acetic acid, shewing the molecular fibres of mucin. See also Plate IV. fig. 1.

Fig. 17. *Pus corpuscles* (p. 69).

Fig. 18. The same after the addition of acetic acid (p. 69).

Fig. 19. *Pus corpuscles.* From the fresh fluid of an abscess, surrounded by a hyaline membrane (p. 69).

Fig. 20. *Blood.* Group of birds' blood corpuscles from the brain, surrounded by a hyaline membrane (p. 69).

Fig. 21. *Blood.* Group of human blood corpuscles from an apoplectic clot, surrounded by a hyaline membrane (p. 64).

Fig. 22. *Granule cells* in masses from softened brain (p. 71).

Fig. 23. *Cancer.* Different forms of cancer cells (p. 71).

Fig. 24. *Tubercle corpuscles* from the lung (p. 72).

Fig. 25. The same after the addition of acetic acid (p. 72).

Fig. 26. *Fat cells* (p. 66).

Fig. 27. *Pigment cells.* *a.* From human lung ; *b.* from the skin of frog ; *c.* from choroid membrane (p. 67).

Fig. 28. *Nerve cells*, varying greatly in form. *a.* Oval, from gasserian ganglion ; *b.* globular, from the same ; *c.* oval, or round, from cerebellum ; *d.* bi-polar, from ganglion of posterior root of spinal nerve ; *e.* multi-polar, from spinal cord ; *f.* branched on one side, from grey matter of cerebellum ; *g.* triangular, from grey matter of cerebrum ; *h.* from sympathetic ganglion of frog, with spiral process, as figured by *Beale* (p. 65).

Fig. 29. *Artificial cells.* Made by mixing protagon with fluids of different densities. *a.* Resembling pus cells ; *b.* finely granular cell, with molecular Brunonian movements ; *c.* nucleated cell ; *d.* cells resembling those of pus surrounded by a hyaline membrane : *e.* compound nucleated cell (p. 45).

FIBROUS ELEMENTS

Plate IV

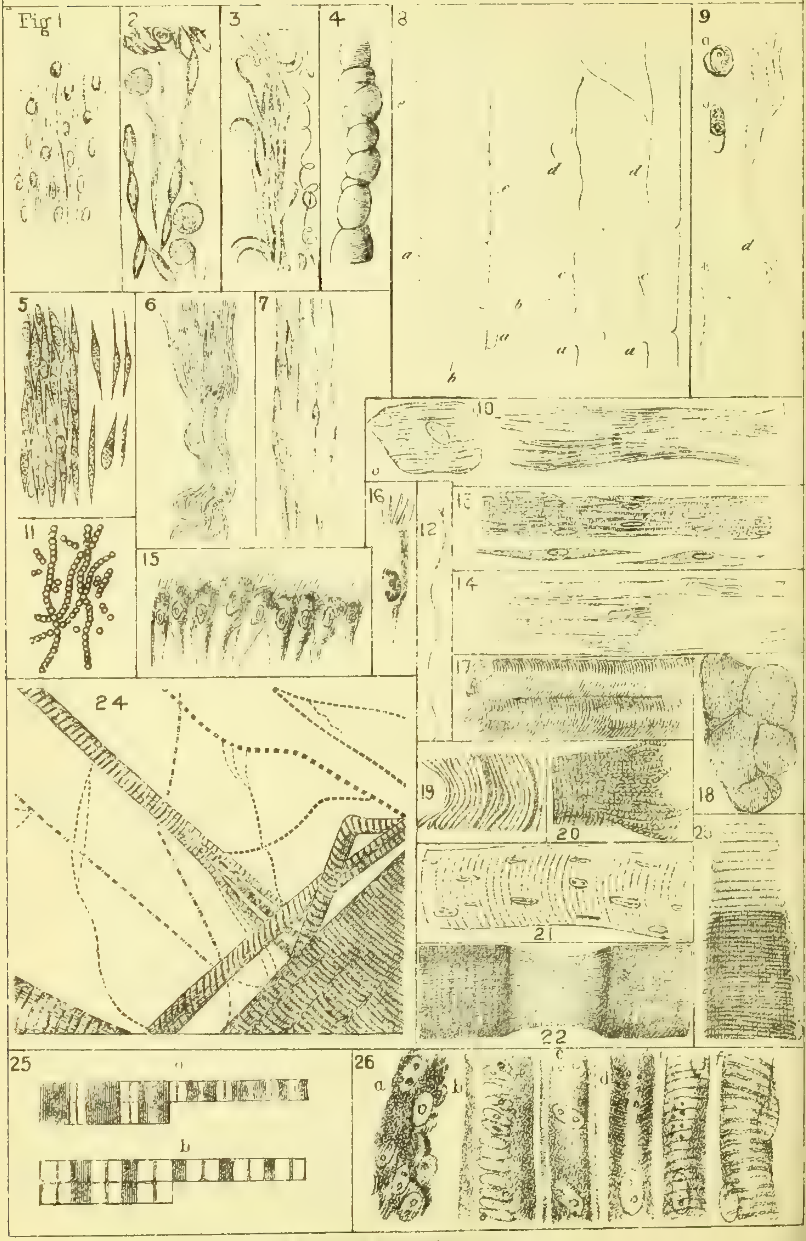

Plate IV.—Fibrous Elements of the Tissues.

Fig. 1. *Molecular fibres,* with interspersed nuclei in mucin (p. 73).

Fig. 2. *Molecular fibres* in blood loaded with fibrin (p. 73).

Fig. 3. *Nuclear,* or *elastic yellow fibres* (p. 76).

Fig. 4. *Spiral elastic fibres* winding round a bundle of white areolar tissue from the base of the brain (p. 76).

Fig. 5. *Cell fibres* formed by aggregation of fusiform cells (p. 76).

Fig. 6. *White areolar fibres* formed by splitting up of fibre cells (p. 77).

Fig. 7. Bundle of the same after the addition of acetic acid (p. 77).

Fig. 8. Diagrammatic view of the development of *nuclear,* or *elastic tissue. a.* Nucleus ; *b.* cell ; *c.* nucleus elongating ; *d.* elongated and branched nuclei in neighbouring cells uniting ; *e e.* nuclei in neighbouring cells, so uniting as to form the spiral (p. 76).

Fig. 9. Development of *white areolar tissue. a.* fibre cell ; *b.* Fibre cell enlarging lengthways ; *f.* still further elongated, a so-called fusiform cell splitting at both ends ; *d.* a fibre cell splitting up at one end, and forming white areolar tissue (p. 76).

Fig. 10. *Histolytic fibres—a.* epidermic cell splitting up with its nucleus ; *b.* epidermic cell transformed into fibres, nucleus having disappeared (p. 78).

Fig. 11. *Molecular contractile fibres,* from a recent infusion (p. 73).

Fig. 12. *Nuclear contractile fibre,* with a rounded molecular head, as in Spermatozöid (p. 76).

Fig. 13. *Contractile cell-fibre,* as in non-voluntary muscle (p. 77).

Fig. 14. The same after the addition of acetic acid (p. 77).

Fig. 15. *Contractile fibres* growing from epithelial cells—*Cilia* (p. 77).

Fig. 16. A ciliated epithelial cell more highly magnified (p. 77).

Fig. 17. *Voluntary muscle.* Voluntary muscular fasciculi, with transverse striæ (p. 73).

Fig. 18. Transverse section of voluntary muscle, shewing polygonal form of fasciculi (p. 73).

Fig. 19. Voluntary muscular fasciculus splitting up transversely (p. 73).

Fig. 20. Voluntary muscular fasciculus splitting up longitudinally (p. 73).

Fig. 21. Voluntary muscular fasciculus after addition of acetic acid (p. 74).

Fig. 22. Voluntary muscular fasciculus ruptured, shewing sarcolemma (p. 73).

Fig. 23. Living voluntary muscular fasciculus after addition of acetic acid, shewing mode of contraction, with sarcolemma at the margin (p. 73).

Fig. 24. Structure of voluntary muscular fibrillæ (p. 74).

Fig. 25. Ultimate fibrillæ magnified 1200 diameters, shewing alternating light and dark spaces, *a* and *b,* in different foci (p. 74).

Fig. 26. *Development of muscular fibre in the embyro. a.* Nuclei embedded in a molecular blastema ; *b.* nuclei arranged in rows, with the external blastema differentiated ; *c.* the nuclei separated, with further differentiated molecular blastema ; *d.* the transverse striæ appearing in the molecular blastema outside and between the nuclei ; *e.* transverse striæ fully crossing the fasciculus ; *f.* the fasciculus perfectly formed (p. 75).

TUBULAR ELEMENTS

Plate V

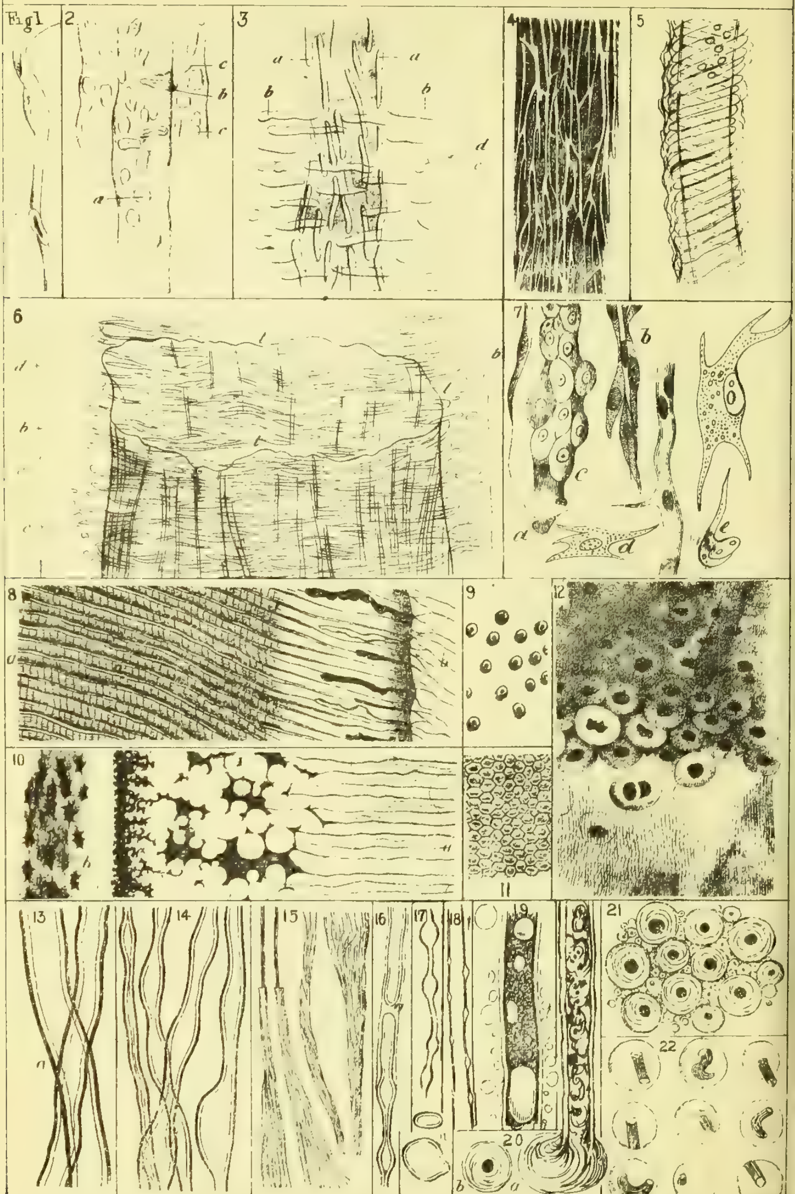

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Plate V.—Tubular Elements of the Tissues.

Fig. 1. *Blood-vessels.* Structure of one of the minutest blood tubes or capillaries. Nuclei irregularly scattered (p. 84).

Fig. 2. *Blood-vessels.* Structure of a small blood tube. *a.* Second or fenestrated membrane; *b.* nuclei arranged transversely; *c.* rounded nuclei (p. 84).

Fig. 3. *Blood-vessels.* Third and fourth muscular layer in a still larger vessel. *a.* Third membrane with longitudinal nuclei; *b.* fourth membrane with transverse nuclei; *c.* external areolar or sixth layer; *d.* transverse section of a nucleus—(p. 84).

Fig. 4. *Blood-vessels.* Elastic coat or fifth membrane of a blood-vessel (p. 84).

Fig. 5. *Blood-vessel.* Spiral arrangement of fusiform cells round a blood tube.—(p. 85.)

Fig. 6. *Blood-vessels.* Third and fourth muscular layer in a vessel twice the diameter of the former one. (Fig. 3) *t, t, t,* Third membrane with longitudinal nuclei, its superior border; *b.* fourth membrane; *c.* its transverse nuclei; *d.* transverse section of one of these (p. 84).

Fig. 7. *Development of blood-vessels.* *a.* Triangular cell uniting itself with the recently formed capillaries; *b.* fusiform cells aggregating together to form a vessel; *c.* layers of cells forming the coats of a blood-vessel; *d.* cell branching to form a vessel; *e* and *f.* similar branching cells in recent exudation (pp. 85, 86).

Fig. 8. *Tooth.* Longitudinal section of enamel. *a.* Enamel; *b.* dentine (p. 87).

Fig. 9. *Tooth.* Transverse section of dental tubes (p. 86).

Fig. 10. *Tooth.* Longitudinal section of dentine and crusta petrosa of tooth. Interglobular substance at the junction of crusta petrosa and dentine. *a.* dentine; *b.* crusta petrosa (pp. 86, 87).

Fig. 11. *Tooth.* Transverse section of enamel (p. 87).

Fig. 12. Transverse section of the grinder of a horse at the junction of crusta petrosa and enamel. The bone cells with their nuclei are seen melting into the crusta petrosa, the latter forming the lacunæ (p. 87).

Fig. 13. Structure of the *nerve tubes* in the senso-motory nerves throughout the body generally, composed 1st, of the *neurilemma* of the nerve tube externally; 2dly, the *white substance of Schwanna;* and, 3dly, in the centre, a viscous fluid which, when coagulated, constitutes the *central axis* (pp. 94, 95).

Fig. 14. *Nerve tubes* from the spinal cord. These are of the same structure, but possess varicosities, and vary greatly in size (p. 95).

Fig. 15. *Nerve tubes* from the spinal cord acted on by water. The white substance of Schwann is coagulated and fibrillated, and the central fluid is now solid, and often projects beyond the lacerated white substance of Schwann (p. 95).

Figs. 16, 17, 18. Similar but smaller *nerve tubes* from the medulla oblongata and brain. Fig. 16. *a.* The neurilemma of the nerve tube is distinctly seen. Fig. 17. Varicose nerve tubes. Fig. 18 are the finest nerve tubes towards the circumference of the cerebrum. Fig. 17. *a*, Globules varying in size and shape, formed of the white substance of Schwann squeezed out of the tube (pp. 95, 96).

Fig. 19. *Nerve tube* after addition of sulphuric ether, shewing loose globules of oil inside, and of ether outside.

Fig. 20. A *nerve tube*, at one end of which, *a*, the central fluid has been squeezed out, forming a coagulated mass with concentric circles. *b.* Transverse section of a nerve tube after steeping in chromic acid and a solution of carmine. There is seen the transverse section of the central rod or axis, surrounded by the concentric laminæ of the white substance of Schwann (pp. 95, 96).

Fig. 21. Transverse section of *white substance of spinal cord*, shewing nerve tubes greatly varying in size, and each exhibiting the dark central axis of the nerve tube highly coloured, surrounded by the fibrillated white substance of Schwann (p. 95).

Fig. 22. Transverse section of *nerve tubes*, shewing portions of the tinted central axis dragged out by a blunt knife.

CARTILAGE AND BONE

Plate VI

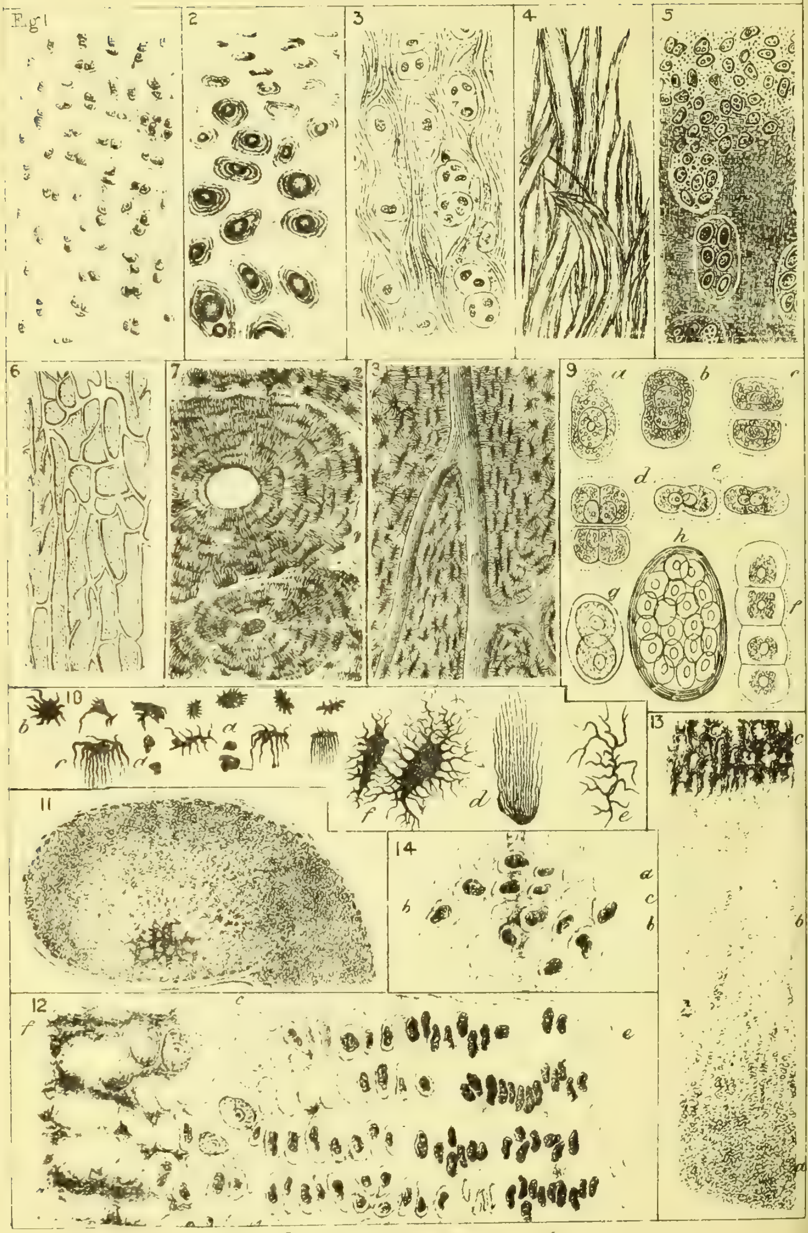


Plate VI.—Structure of Cartilage and Bone

Fig. 1. *Cartilage.* Section through the articular surface of a metatarsal bone, 100 diameters linear (p. 88).

Fig. 2. *Cartilage.* Section of a cartilage of a rabbit's ear. 250 d. (p. 89).

Fig. 3. *Fibro-cartilage.* 250 d. (p. 89).

Fig. 4. *Diseased cartilage.*—Fibrous degeneration of cartilage from diseased joint. 250 d. (p. 89).

Fig. 5. *Diseased cartilage.* Endogenous multiplication and bursting of cells in pulpy degeneration of articular cartilage. 250 d. (p. 89).

Fig. 6. *Bone.* Vertical section of a long bone, shewing Haversian canals, and their anastomoses. 20 d. (p. 90).

Fig 7. *Bone.* Tranverse section of a long bone. 250 d. (p. 90).

Fig. 8. *Bone.* Vertical section of a long bone. 250 d. (p. 90).

Fig. 9. *Cartilage cells.* *a, b, c, d, e, f.* Fissiparous multiplication in articular surface of a long bone (p. 88); *g h.* Endogenous multiplication from a velvety or diseased cartilage of the femur. 400 d. (p. 89)

Fig. 10. *Various forms of lacunæ and canaliculi in bone.* *a a.* Simple irregular cavities from an ossification of the pleura; *b.* from human bone; *c.* a lacuna next the Haversian canal, with most of its canaliculi towards the canal; *d.* lacunæ and canaliculi from the boa, also next the Haversian canal; *e.* canaliculi without a lacuna. 250 d.; *f.* lacunæ and canaliculi shewing their mode of anastomosis. 500 d. (p. 91).

Fig. 11. *Ossification.* Transverse section through a portion of fœtal vertebral bone shewing commencement of ossification. 40 d. (pp. 93, 94).

Fig. 12. *Ossification.* Vertical section through the epiphysis of the tibia of a new-born kitten. *a.* Cartilage cells arranged in rows; *b.* cartilage cells shrunk within their cavities; *c.* cartilage cells still filling the cavities; *d. e.* cartilage cells on the surface; *f.* calcareous ridges between rows of cartilage cells, forming cancelli and Haversian canals. 250 d. (pp. 93, 94).

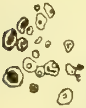
Fig. 13. *Ossification.* Vertical section through a fœtal long bone shewing commencement of ossification. *a.* cartilage; *b.* cartilage cells arranged in rows; *c.* mineral matter deposited between them. 40 d. (pp. 93, 94).

Fig. 14. *Ossification.* Transverse section through ossifying cartilage of a calf. *a.* Empty cartilage spaces; *b.* shrunken cartilage cells breaking down; *c.* transverse section of calcareous ridges. 250 d. (p. 93, 94).

MOLECULAR THEORY

Plate VII

Fig 1



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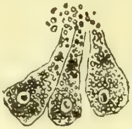

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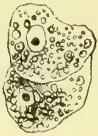

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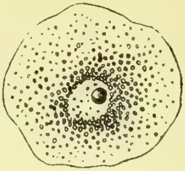

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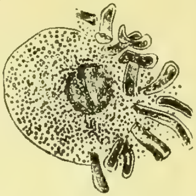

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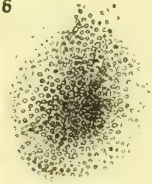

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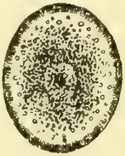

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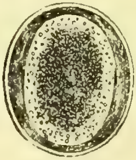

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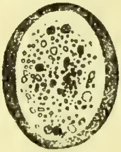

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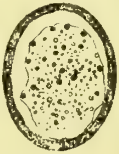

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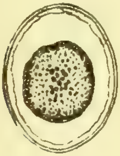

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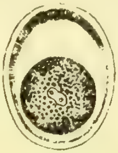

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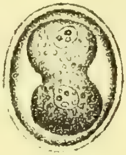

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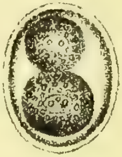

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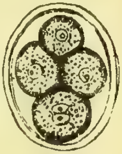

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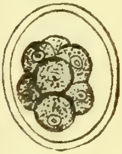

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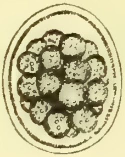

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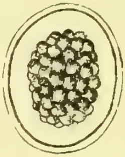

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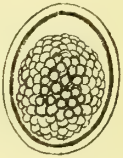

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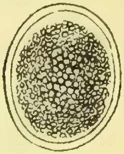

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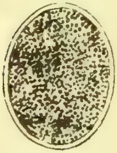

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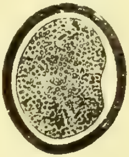

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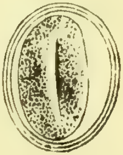

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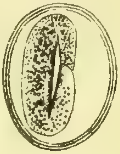

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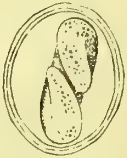

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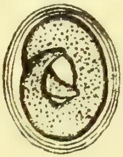

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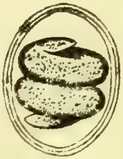

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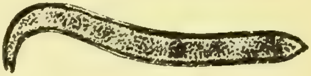

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Plate VII.—Molecular Theory of Organisation, as Illustrated by Development of Ascaris Mystax, after Nelson.

[*See Philosophical Transactions of London,* vol. 142, 1852 (pp. 48–49, *et seq.*)].

Figs. 1 to 4 Represent the histogenetic changes which take place among the molecules deposited in the ovarian tube of the female worm, until the fully maturated ovum (Fig. 4) passes into the oviduct.

Fig. 5. Contact with, and entrance of, the spermatozoids into the ovum. This, the act of impregnation, is followed by gradual solution of the spermatozoids, while the germinal vesicle is still visible.

Fig. 6. This also soon dissolves, and the interior of the ovum is now reduced to a mass of histolytic molecules. Some spermatozoids still undissolved.

Fig. 7. Formation of a chorion externally—spermatozoids dissolved—germinal vesicle still visible.

Fig. 8. Both spermatozoids and germinal vesicle fully dissolved. The histolytic molecules dense in the centre, but beginning to clear up at the circumference.

Figs. 9, 10 shew these molecules clearing up still further, when they meet together, concentrate themselves, and form histogenetic molecules.

Figs. 10, 11 shew this process completed, and a membrane forming round them, another included cell is developed, as in Figs. 11 and 12.

Fig. 12 shews the nucleus beginning to divide.

Fig. 13. The cell now dividing into two.

Fig. 14. The division complete.

Fig. 15. Each half separated into other two.

Figs. 16, 17, 18, 19, 20. The process of division is seen going on in these figures, until another histolytic mass of molecules is produced in Fig. 20.

Fig. 21. This mass begins to clear up by coalescence of the molecules, which again become histogenetic.

Fig. 22. They have now united together, and concentrated themselves, and begin to separate from the vitelline membrane.

Fig. 23. A cup-shaped depression now appears, which, passing through the mass, forms a ring.

Fig. 24. This ring is now seen to be divided at one place.

Fig. 25. The two ends of the ring now elongate, and cross one another, and the molecules go on coalescing, to form the body of the worm.

Figs. 26, 27. The worm now becomes spiral, and, on the bursting of the vitelline wall,

Fig. 28. The perfect animal is extruded.

PHYSICAL PROPERTIES, Plate VIII

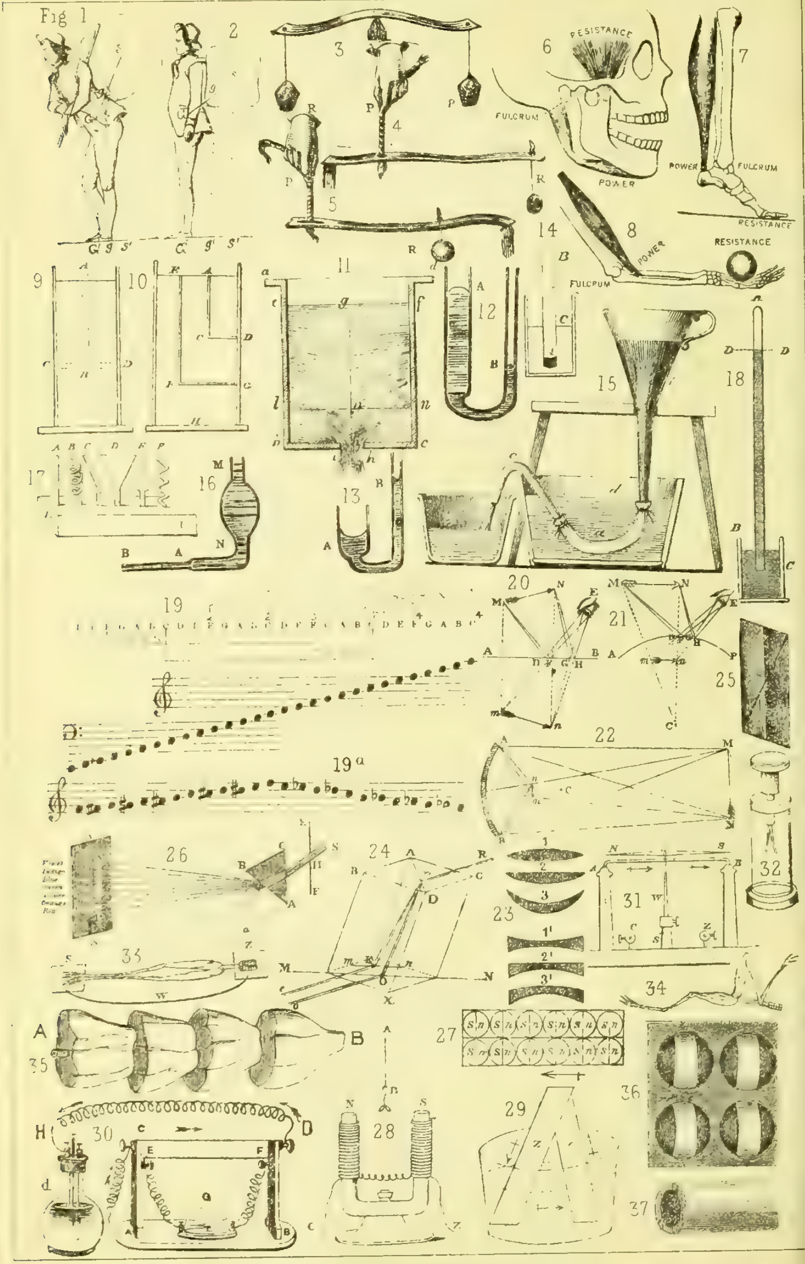

Plate VIII.—Physical Properties of the Tissues.

Figs. 1, 2. Diagram shewing the centre of gravity in a man with and without a burden on his back (p. 107).

Fig. 3. Diagram of a lever of the 1st order; R, resistance; P, power; Fulcrum in the centre (p. 112).

Fig. 4. Diagram of a lever of the 3d order: P, power; R, resistance (p. 112).

Fig. 5. Diagram of a lever of the 2d order; P, power; R, resistance (p. 112).

Fig. 6. An example of the 2d order of lever in the body, as seen in movements of lower jaw in opening the mouth. Resistance is temporal muscle; Fulcrum is the glenoid cavity in temporal bone; Power is anterior belly of the digastric (p. 112).

Fig. 7. An example of the 1st order of lever as seen in the act of walking. Resistance is the ground; Fulcrum is the upper surface of the astragalus; and Power is the tendo-achilles (p. 112).

Fig. 8. An example of the 3d order of lever, as seen in flexion at the elbow joint. Resistance is the hand, with or without a weight; Fulcrum is the trochlear surface of the humerus; and Power is the biceps inserted into tubercle of radius (p. 113).

Fig. 9. Diagram illustrating Pascal's law of the equality of fluid pressure (p. 114).

Fig. 10. Diagram shewing that the pressure of a fluid on any portion of the inner surface of a containing vessel is in proportion to its depth beneath the surface (p. 114).

Fig. 11. Diagram illustrating Torricelli's law that the velocity of the efflux of a fluid is determined by the degree of pressure (p. 119).

Fig. 12. *Capillarity.* Bent glass tube containing *mercury* in equilibrium in the two limbs, shewing that the upper surfaces of the liquid are convex, the tube not being wetted by the mercury (p. 116).

Fig. 13. A similar tube containing *water*, the upper surfaces of the fluid concave, the tube being wetted by the water (p. 116).

Fig. 14. An endosmometer; B, tube having a membrane, A, tied over one end, and immersed in vessel C (p. 116).

Fig. 15. Apparatus to illustrate the phenomena of diffusion through a blood-vessel along which fluid is flowing (p. 118).

Fig. 16. Poisseulle's tube for experiments upon the discharge of fluids through fine tubes (p 119).

Fig. 17. Arrangement of variously formed tubes, A, B, C, D, E, and F, all communicating with the reservoir L U, to shew hydrostatic equilibrium (p. 115).

Fig. 18. A barometer. A, tube; B C, cistern containing mercury; D D, level of mercury in tube (p. 121).

Fig. 19. Diagram shewing the ranges of the different varieties of the human voice (p.133).

Fig. 19^a A chromatic scale formed of semitones, shewing the sharps and flats of the natural notes (p. 133).

Fig. 20. Diagram shewing reflection from a plane mirror. A B, plane of mirror; E, eye of observer; M N, object from which the pencils of rays, M D, M F, N G, H, proceed; N M N, the object as seen in the mirror (p. 135).

Fig. 21. Diagram shewing reflection from a convex mirror. A B, The surface of the mirror; E, eye of observer; M N, object; *m n*, object as seen *behind* the mirror reduced in size (p. 135).

Fig. 22. Diagram shewing reflection from a concave mirror. A B, Surface of the mirror; M N, object; *m n*, reflected image reduced in size, inverted, and *before* the mirror (p. 135).

Fig. 23. Various forms of lenses: 1. double convex; 2. plano-convex; 3. concavo-convex; 1^1. double concave; 2^1. plano-concave; 3^1. concavo-concave (p. 137).

Fig. 24. Crystal of Iceland spar shewing double refraction. See description (p. 142).

Fig. 25. Nichol's prism for throwing out one of the rays of polarised light (p. 142).

Fig. 26. Arrangement to shew the refrangibility of light. E F, Shutter; H, aperture in the same; A B C, prism of glass; S, ray of light which, instead of proceeding in the direction of the dotted lines, is refracted so as to form the spectrum, M N, shewing the prismatic colours (p. 138).

Fig. 27. Diagram shewing that a magnet may be regarded as composed of hypothetical molecules having southern and northern polarities (p. 145).

Fig. 28. Arrangement to illustrate diamagnetism (p. 146).

Fig. 29. Arrangement to shew the production of a current of voltaic electricity arising from the action of a fluid on one of two heterogeneous metals. Z, zinc plate; C, copper plate. Arrows shew direction of the current (p. 150).

Fig. 30. Arrangement to shew the production of an induced or Faradic current of electricity. *d.* A bichromate of potash battery (p. 155).

Fig. 31. Arrangement to shew the influence of an electric current on the magnetic needle, N S (p. 148).

Fig. 32. A gold leaf electroscope (p. 148).

Fig. 33. Galvani's experiment (p. 162).

Fig. 34. Experiment of Galvani, Aldini, and Humboldt, shewing contractions in a prepared frog's leg, without the agency of metals or a metallic arc, simply by bringing the leg in contact with the lumbar nerves (p. 164).

Fig. 35. Matteucci's pile of frogs' legs for the production of a current of electricity. A, Femur divided; B, knee-joint (p. 166).

Fig. 36. Diagrammatic view of Du-Bois Reymond's hypothetical peripolar electrical molecules of which he believes muscular fibre is composed (p. 167).

Fig. 37. Diagrammatic view of Dr Radcliffe's hypothetical electrical cylinders composing muscular fibre, shewing a central nucleus or rod manifesting negative electricity surrounded by a positively electrified covering (p. 167).

DIGESTIVE SYSTEM

Plate IX

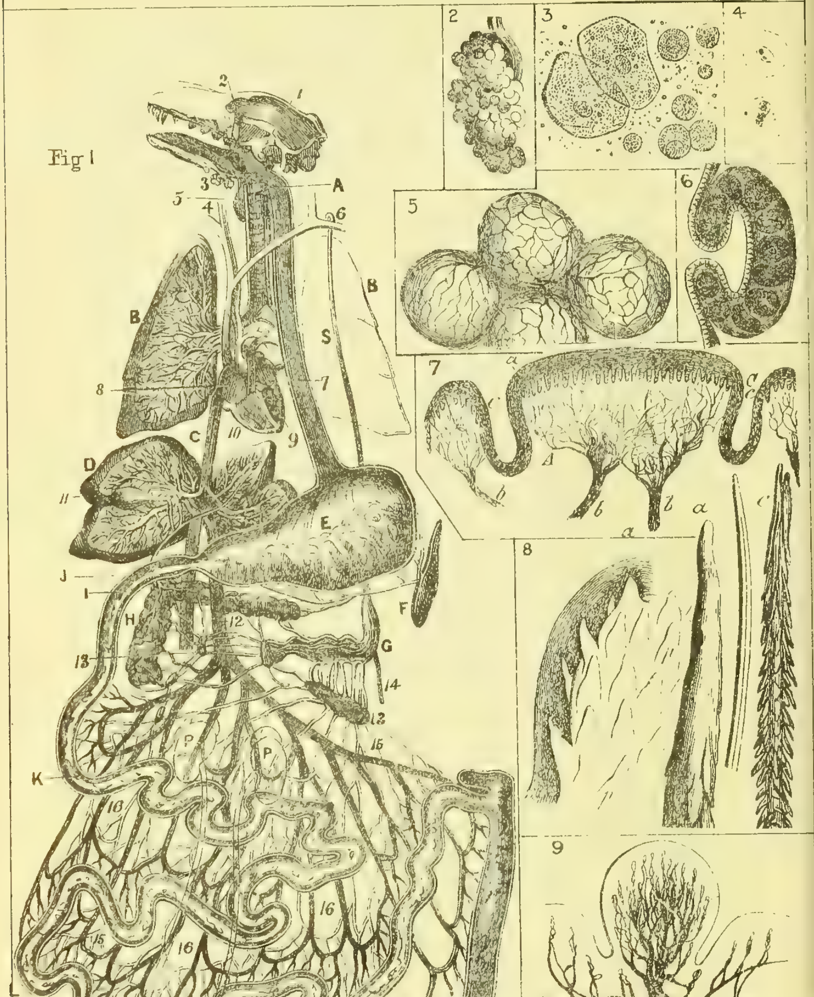

Plate IX.—Function of Nutrition.

Fig. 1. View of the nutritive system of a dog—modified from *Bernard.* A. Œsophagus. B. Lungs. C. Vena cava. D. Liver, E. Stomach. F. Spleen. G. Receptaculum chyli. H. Pancreas. I. Duodenum. J. Entrance of biliary and hepatic duct. K. Jejunum. L. Ileum. M. Cæcum. N. Colon. O. Rectum. P. Kidneys, with the supra-renal capsules above. R. Urinary bladder. S. Thoracic duct, through which the chyle passes to join the blood. 1. Parotid gland. 2. Salivary gland of Nuck. 3. Submaxillary and other salivary glands. 4. Jugular and subclavian veins. 5. Situation of thymus and thyroid glands. 6. Entrance of the thoracic duct into the left subclavian vein, near the jugular. 7. Left auricle. 8. Right auricle. 9. Left ventricle. 10. Right ventricle. 11. Gall bladder. 12. Vena portæ, which conveys blood from the intestines to the liver. 13. Mesenteric glands. 14. Lymphatic vessels. 15. Lacteal vessels. 16. Branches of the portal vein. 17. Ureters.

Fig. 2. Structure of lobule of parotid gland with its duct. 20 diam.

Fig. 3. Epithelial flattened cells, and globular salivary cells, and molecules in the saliva. 250 diam.

Fig. 4. Action of acetic acid on two salivary cells.

Fig. 5. Closed follicles covered with blood vessels in the tonsil. 60 diam. (*Kölliker.*)

Fig. 6. Follicular gland from the root of the human tongue, containing closed follicles. *a, a.* epithelium ; *b.* surface of follicular gland ; *c.* cavity of the gland ; *d.* follicle in the thick wall of the gland. 20 diam. (*Kölliker.*)

Fig. 7. Vertical section of a human circumvallate papilla. A. central papilla ; B B. circumvallate papilla ; C C. Depression, or fossa surrounding the central papilla ; *a.* epithelium ; *b. b.* nerves of the papilla ; *c.* secondary papilla. 10 diam. (*Kölliker.*)

Fig. 8. Fungiform papilla of the human tongue. *o.* epithelium ; *p.* secondary papilla. 10 diam. (*Kölliker.*) *a, b, c.* elongated filiform papillæ of the human tongue. 160 diam. (*Todd and Bowman.*)

Fig. 9. Section of fungiform papilla, shewing distribution of : *a.* artery, and *v.* vein, forming capillary loops. 18 diam. (*Todd and Bowman.*)

Fig. 10. Mucous glands and ducts in the œsophagus. 25 diam. (*Donders.*)

DIGESTION & CHYLIFICATION. Plate X

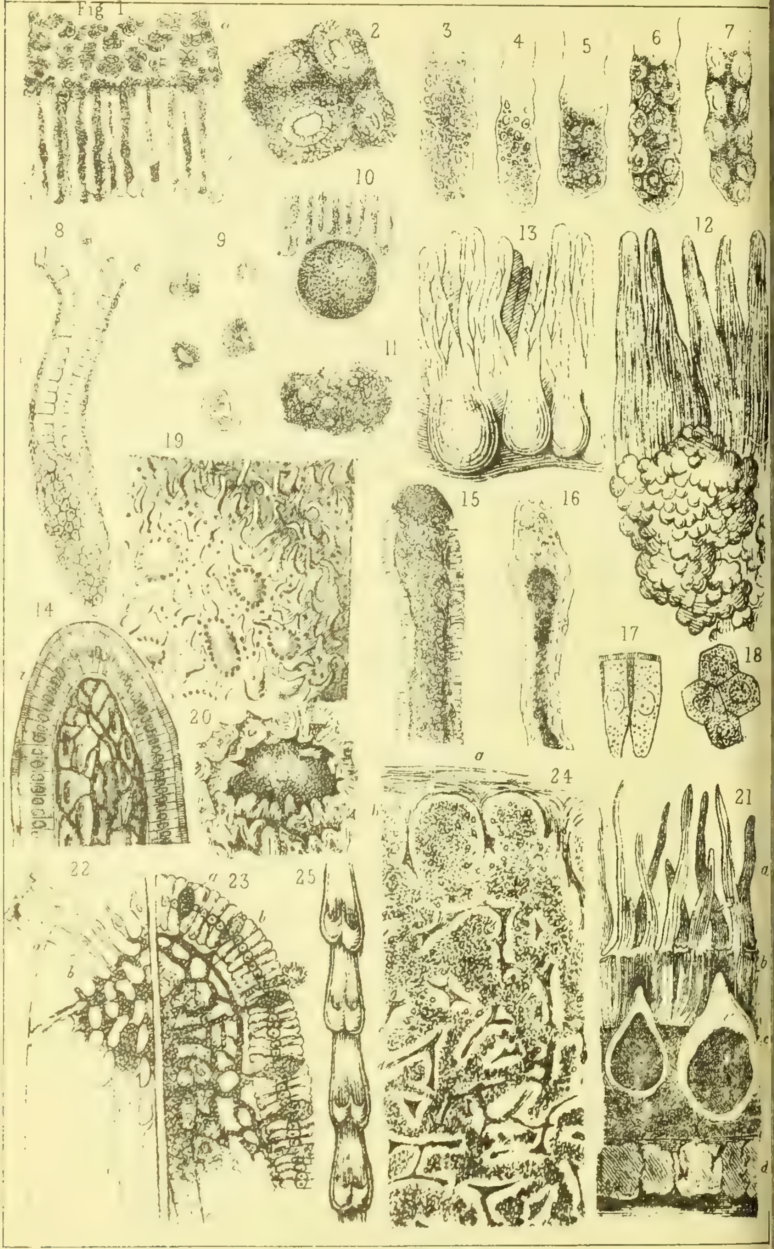

Plate X.—Digestion and Chylification.

Fig. 1. Section of mucous membrane of the stomach, shewing above, *a*, follicular depressions, and below, *b*, the gastric follicles. 10 diam. (***Frerichs.***)

Fig. 2. Follicular depression, with the opening of four follicles on surface of mucous membrane of the stomach. 200 diam. (***Frerichs.***)

Figs. 3–7. The terminal or secreting end of gastric follicles, with the gastric cells in various stages of formation: (3) molecular contents; (4 and 5) formation of nuclei; (6 and 7) formation of gastric cells. 200 diam. (***Frerichs.***)

Fig. 8. Structure of a gastric follicle, cut obliquely, shewing above; *a*. section of cylindrical epithelium; *b*. seen from above. 250 diam. (***Wasmann.***)

Fig. 9. Isolated cells from gastric follicles. (***Frerichs.***)

Fig. 10. A large Peyer's gland occasionally seen below the gastric follicles. 15 diam. (***Frerichs.***)

Fig. 11. Portion of the contents of the same, shewing molecules, nuclei, and cells. 200 diam.

Fig. 12. Glands of Brunner below the villi in the duodenum. 20 diam. (***Frerichs.***)

Fig. 13. Glands of Peyer below villi of small intestine. 20 diam. (***Frerichs.***)

Fig. 14. Extremity of a villus shewing columnar epithelium, vessels, and commencement of lacteal duct. *a*. fine lines at the external margin of epithelial cells. 400 diam. (*Leydig.*)

Fig. 15. Villus of small intestine, the extremity and centre filled with fatty molecules during absorption. 200 diam. (*Frerichs.*)

Fig. 16. Villus without epithelium, having lacteal distended with molecular matter. 200 diam. (*Frerichs.*)

Fig. 17. Structure of epithelial cells from intestinal villus, shewing their lateral adhesion—the external layer with fine lines. 500 diam. (*Frey.*)

Fig. 18. Group of four epithelium cells from intestinal villus, seen from above. 500 diam. (*Frey.*)

Fig. 19. An aggregate patch of Peyer shewing follicles, shut sacs, and villi. 10 diam. (*Bœhm.*)

Fig. 20. A solitary gland of Peyer surrounded by villi with their chyle ducts. 30 diam. (*Teichmann.*)

Fig. 21. Vertical section through a patch of Peyer's glands. *a*. villi; *b*. glands of Lieberkühn; *c*. Peyer's saccular glands cut open; *d*. muscular and peritoneal coats. 200 diam. (*Todd and Bowman.*)

Fig. 22. Diagram representing origin of lacteals in a villus, according to *Funke*. *a*. epithelial cells; *b*. supposed connective tissue corpuscles; *c*. central lacteal.

Fig. 23. Another view of the same with flask-shaped bodies, described by Max Schultze, according to *Letzerich*. *a*. flask-shaped body communicating with *b*, a delicate plexus that enters the lacteal, *c*.

Fig. 24. A vertical section of a lymphatic gland. *a*. capsule; *b*. lymph sacs; *c*. lymph channel; *d*. trabeculæ.

Fig. 25. Lymphatic vessel cut open to shew its valves.

SANGUIFICATION & CIRCULATION. Plate XI

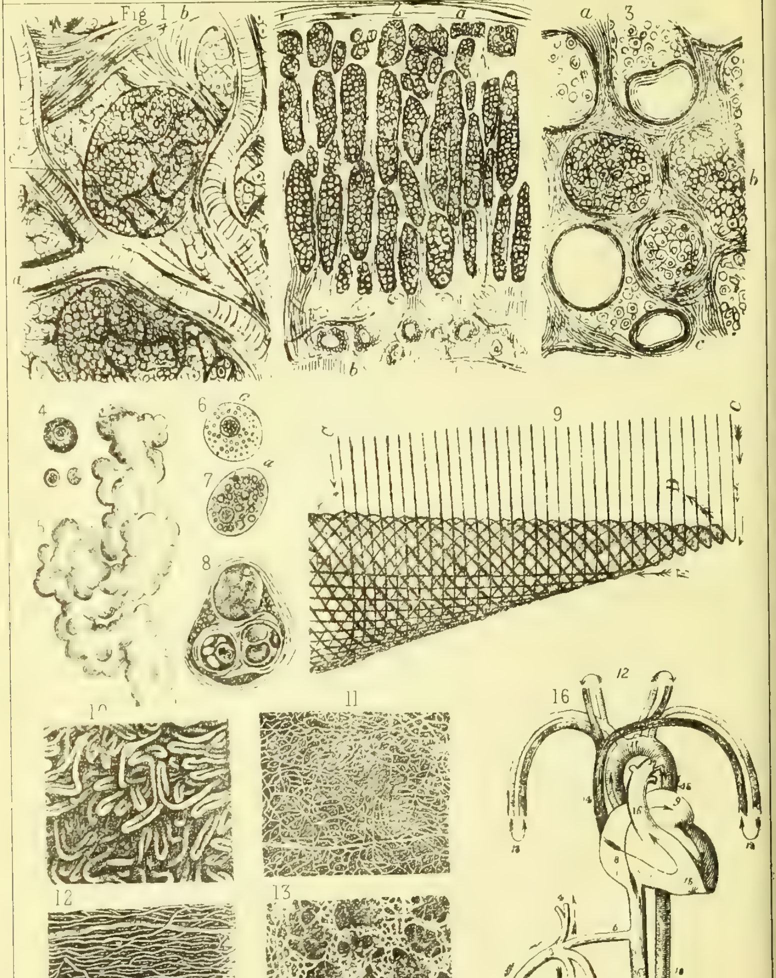

Plate XI.—Sanguification and Circulation.

Fig. 1. Structure of the spleen. *a.* Artery; *b.* trabeculæ; *c.* Malpighian body, with lymphatic elements; *d.* spleen pulp. 20 diam. (*Leydig.*)

Fig. 2. Structure of the supra-renal capsule. *a.* Cortical portion—the shut sacs, containing lymphatic elements; *b.* medullary portions. 200 diam.

Fig. 3. Structure of the thyroid gland. *a.* Fibrous stroma; *b.* shut sacs, with lymphatic elements; *c.* colloid matter in the interior of the sacs. 200 diam.

Figs. 4–8. Structure of the thymus. 4, 6, 7. Cell and nuclear elements of fluid; 400 diam. 5. Follicular structure; 10 diam. 8. Compound cellular body, surrounded by a concentric capsule, 400th of an inch in its long diameter. (*Ecker.*)

Fig. 9. A cone, produced by rolling a sheet of net, with dark lines, upon itself, to represent the course of the muscular laminæ in the ventricle of the heart. It shews the fourth central, or transverse, layer, and the three internal layers. C, C. Transverse middle layer. D, E. External oblique and vertical layers, from conical winding of C, C. (*Pettigrew.*)

Figs. 10–15. Capillary networks. 10. In papillæ of lips; 11. in areolar tissue; 12. in muscle; 13. in lung; 14. in fungiform papilla of tongue; 15. in mucous membrane surrounding follicles. 25 diam. (*Berres.*)

Fig. 16. Diagram of the fœtal circulation. 1. The umbilical cord, consisting of the umbilical vein and two umbilical arteries, proceeding from the placenta (2). 3. The umbilical vein, dividing into three branches: two (4, 4) to be distributed to the liver; and one (5), the *ductus venosus*, which enters the inferior vena cava (6). 7. The portal vein, returning the blood from the intestines, and uniting with the right hepatic branch. 8. The right auricle; the course of the blood is denoted by the arrow proceeding from 8 to 9, the left auricle. 10. The left ventricle; the blood following the arrow to the arch of the aorta (11), to be distributed through the branches given off by the arch to the head and upper extremities. The arrows 12 and 13 represent the return of the blood from the head and upper extremities through the jugular and subclavian veins, to the superior vena cava (14), to the right auricle (8), and in the course of the arrow through the right ventricle (15), to the pulmonary artery (16). 17. The *ductus arteriosus*, which appears to be a proper continuation of the pulmonary artery; the offsets at each side are the right and left pulmonary arteries cut off. The ductus arteriosus joins the descending aorta (18, 18), which divides into the common iliacs, and these into the internal iliacs, which become the umbilical arteries (19), and return the blood along the umbilical cord to the placenta and the external iliacs (20), which are continued into the lower extremities. The arrows at the termination of these vessels mark the return of the venous blood by the veins to the inferior cava. (*Erasmus Wilson.*)

RESPIRATION & SECRETION. Plate XII

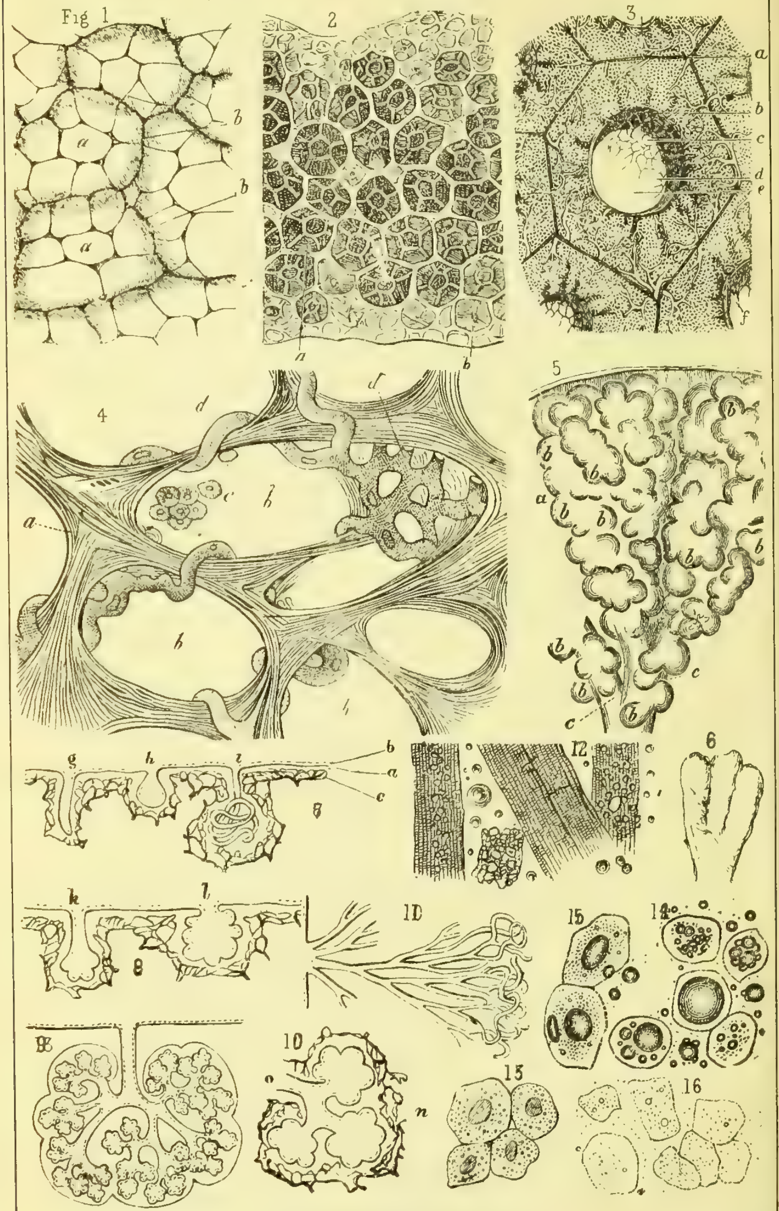

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Plate XII.—Respiration and Secretion.

Fig. 1. External surface of the lung. *a.* Air cells ; *b, b.* borders of the smallest lobules. 30 diam. (*Harting.*)

Fig. 2. Internal surface of section of lung, shewing air vesicles. *a.* Deep seated ; *b.* towards the margin. 30 diam. (*Rossignol.*)

Fig. 3. Slightly oblique section of injected bird's lung. *a.* Spaces between contiguous lobules, containing terminal pulmonary arteries, and veins supplying the capillary plexus ; *b.* lining membrane of bronchial tube ; *c.* blood-vessels, with large areolæ, *d,* in bronchial membrane ; *e.* cavity of bronchial tube ; *f.* very fine dense capillary plexus. 25 diam. (*Rainey.*)

Fig. 4. Thin section of pulmonary substance. *a.* Fibrous tissue ; *b, b, b.* cut air cells ; *c.* group of epithelial cells, from lining membrane of air cells ; *d, d.* capillary blood-vessels lining air vesicle below epithelial membrane. 250 diam. (*Ecker.*)

Fig. 5. Two small pulmonary lobules. *a, b, b, b.* Air cells ; *c.* terminal bronchial twigs. 25 diam. (*Kölliker.*)

Fig. 6. Mode of termination of bronchial tubes in air vesicles of the lung, according to *Waters* of Liverpool.

Figs. 7–11. Diagrams of secreting glands. 7. *a.* Basement membrane ; *b.* epithelium ; *c.* blood-vessels ; *g.* straight folilcle ; *h.* saccular follicle ; *i.* coiled tube : 8, *k.* tubular crypt ; *l.* saccular crypt : 9. racemose or compound gland : 10. a lobule of the same enlarged ; *n.* lobule ; *o.* terminal duct : 11. compound tubular gland. (*Sharpey.*)

Fig. 12. Fatty degeneration of muscle. 250 diam.

Fig. 13. Group of hepatic cells. 250 diam.

Figs. 14 and 15. Fatty degeneration of hepatic cells. 250 diam.

Fig. 16. Waxy degeneration of hepatic cells.

EXCRETION BY LIVER & KIDNEYS. Plate XIII

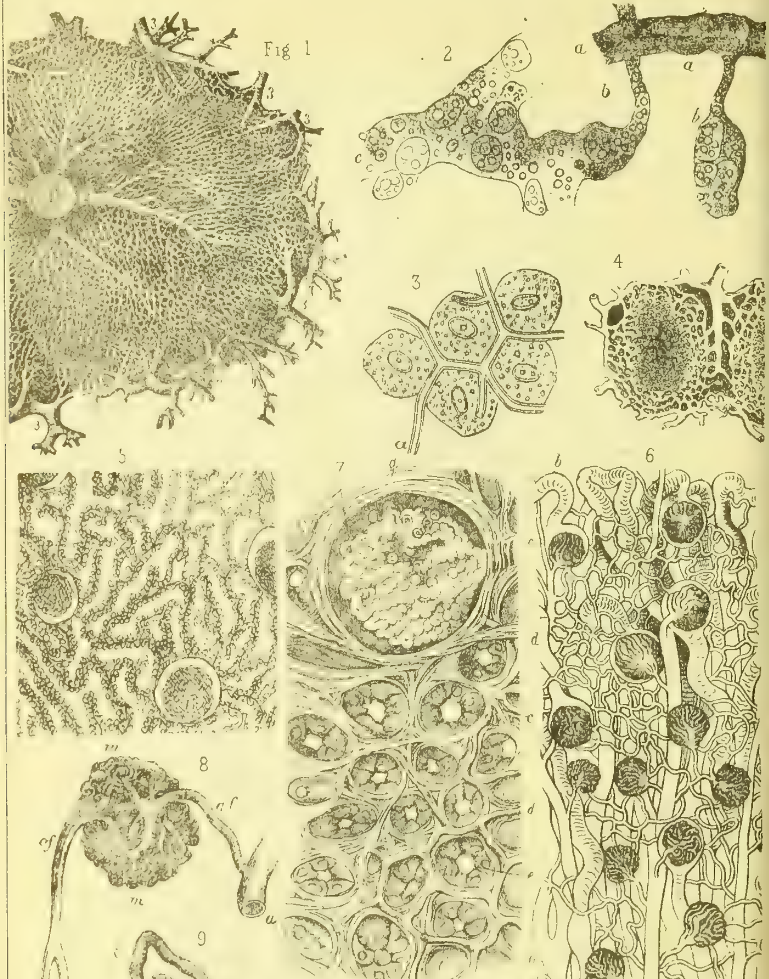


Plate XIII.—Excretion by Liver and Kidneys.

Fig. 1. Transverse section of a lobule of the human liver, in which the vessels have been fully injected. 1. Intralobular or hepatic vein; 2. Its smaller branches, collecting blood from the capillary network ; 3. Interlobular or portal veins, passing into the lobule. 60 diam. (*Sappey.*)

Fig. 2. Terminal bile duct. *a.* Small branch of interlobular hepatic duct ; *b.* smallest biliary duct, communicating with others in which cells are seen. 215 diam. (*Beale.*)

Fig. 3. Small fragment of a hepatic lobule, in which the smallest intercellular biliary ducts (*a*) were filled with colouring matter during life. 500 diam. (*Chrzonszczewsky.*)

Fig. 4. Two lobules of the liver, in which the biliary ducts are represented as originating in a plexus towards their exterior. 20 diam. (*Kiernan.*)

Fig. 5. Section of cortical substance of kidney, shewing Malpighian bodies, and their capsules, and the convoluted tubes. 20 diam. (*Dickinson.*)

Fig. 6. Injected portion of cortical and medullary structure of kidney. *a.* Tubuli uriniferi ; *b.* their termination, by expanding over the Malpighian body ; *c, d.* capillary plexus. 25 diam. (*Ecker.*)

Fig. 7. Malpighian body, *b.* and its capsule, *a* ; *c.* bands of fibres between the tubes ; *d.* capillary vessels ; *e.* epithelium lining the tubes. 250 diam. (*Ecker.*)

Fig. 8. Blood-vessels forming Malpighian body. *a.* Terminal renal artery ; *af.* afferent branch, going to Malpighian body ; *m, m.* plexus of vessels forming Malpighian body ; *ef.* efferent branch, coming from Malpighian body, dividing into capillaries, *b.*, which furnish the tubes. 50 diam. (*Bowman.*)

Fig. 9. Malpighian capsule and uriniferous tube. *b.* Artery passing into Malpighian body ; *d.* capsule distended by injection, which fills the uriniferous tube in connection with it, *c.* 30 diam. (*Bowman.*)

Fig. 10. Uriniferous tube, lined with epithelial cells, in medullary portion of kidney. 250 diam.

Fig. 11. Uriniferous tube in cortical substance of kidney, containing nuclei and molecular matter. 250 diam.

Fig. 12. Commencing fatty degeneration of uriniferous tube. 250 diam.

Fig. 13. Advanced fatty degeneration of uriniferous tube. 250 diam.

EXCRETION BY THE SKIN.

Plate XIV

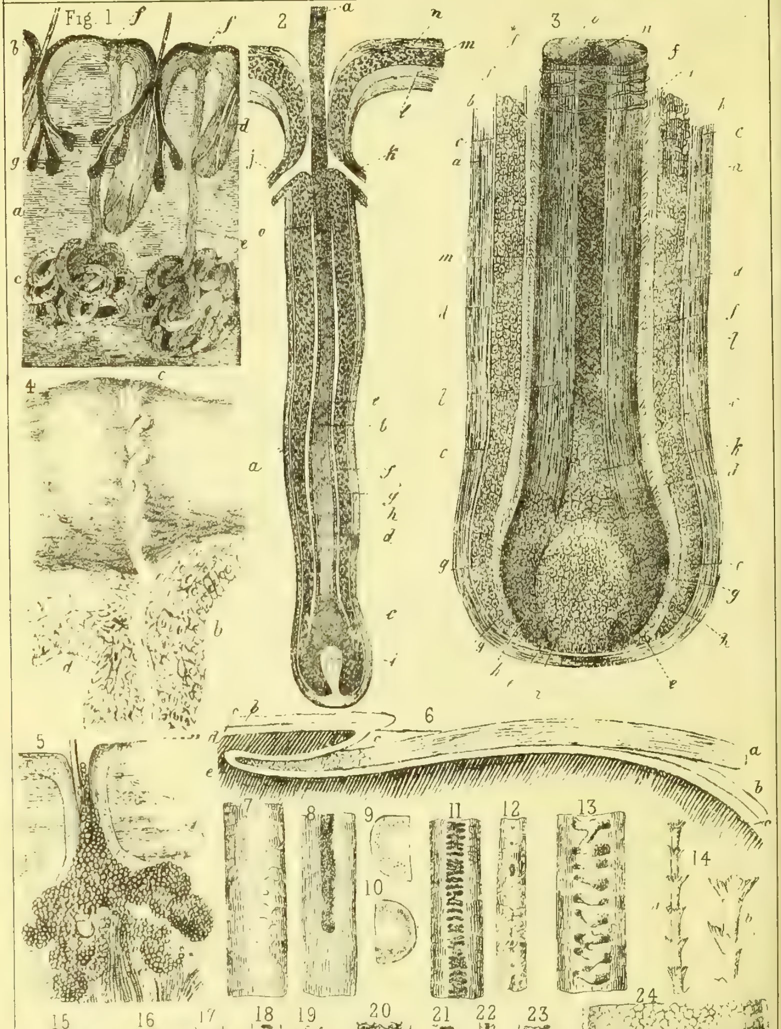


Plate XIV.—Excretion by the Skin.

Fig. 1. Vertical section through the skin. *a.* Corium ; *b.* epidermis ; *c.* sudoriparous glands ; *d.* hair sac ; *e.* straight ducts from sweat glands ; *f, f.* their openings on the surface of skin ; *g.* sebaceous glands. 30 diam. (*Kölliker.*)

Fig. 2. Hair and hair sac. *a.* Hair shaft ; *b.* root of hair ; *c.* bulb of hair ; *d.* epidermis of hair ; *e.* inner root sheath ; *f.* outer root sheath ; *g.* structureless membrane of hair sac ; *h.* transverse and longitudinal fibrous layer ; *i.* papilla of hair ; *k.* excretory ducts of the sebaceous glands ; *j.* its epithelium ; *l.* cutis at aperture of hair sac ; *m.* lower or coloured portion of epidermis ; *n.* external layer of epidermis ; *o.* end of inner root sheath. 50 diam. (*Kölliker.*)

Fig. 3. Hair root and hair sac. *a.* External fibrous sac ; *b.* structureless membrane ; *c.* the outer, and *d.* the inner root sheath ; *e.* junction of the outer sheath, *c.*, with the hair bulb ; *f.* external layer of hair ; *f**. transverse fibres ; *g.* lower portion of the same ; *h.* cells of the hair root ; *i.* hair papilla ; *k.* cells of medulla ; *l.* fibrous shaft ; *m.* medulla containing air ; *n.* transverse section of medulla, and *o.* of the shaft. 300 diam. (*Frey.*)

Fig. 4. Section of skin of heel. *a.* External epidermic layer ; *b.* internal epidermic layer ; *c.* spiral termination of sudoriparous duct ; *d.* position of papilla of cutis. 150 diam. (*Leydig.*)

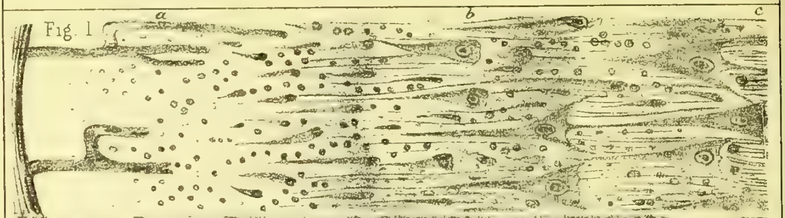
Fig. 5. Large sebaceous gland from skin of nose, opening into a hair follicle containing fatty matter. 50 diam. (*Ecker.*)

Fig. 6. Longitudinal section through the middle of the nail and bed of the nail. *a.* Free edge of proper substance of the nail ; *b.* external epidermis of finger ; *c.* internal epidermis ; *d.* bed of nail ; *e.* follicle or root. 8 diam.

Figs. 7–25. Structure of various kinds of hair. 7. Imbricated human hair ; 8. human hair with central medulla ; 9. and 10. sections of human hair ; 11. hair of an Indian monkey ; 12. hair of camel ; 13. hair of lemur ; 14. hair of an Indian bat —*a.* low, *b.* higher power ; 15. hair of polar bear ; 16. wool of sheep ; 17. hair of lion ; 18. and 19. hair of kangaroo ; 20. and 21. hair of rabbit ; 22. hair of mouse ; 23. hair of armadillo ; 24. hair of musk deer ; 25. fibrous human hair. 100 diam

NERVOUS SYSTEM. Plate XV

Fig. 1



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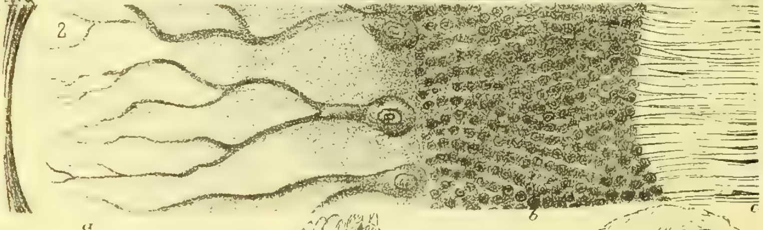

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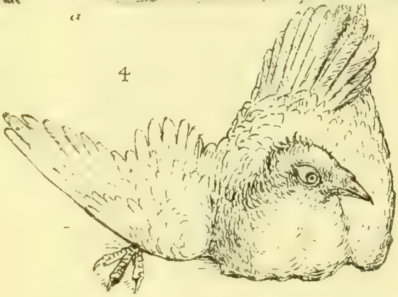

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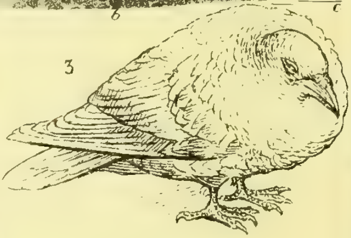

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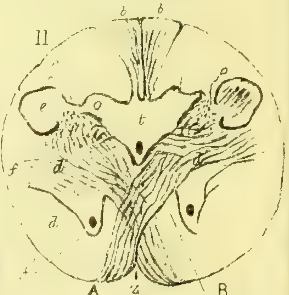

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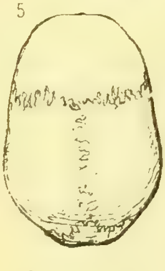

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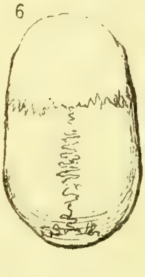

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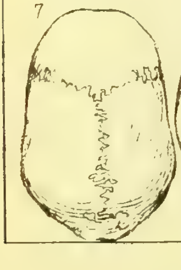

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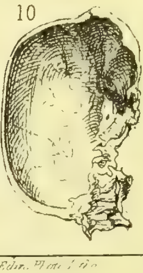

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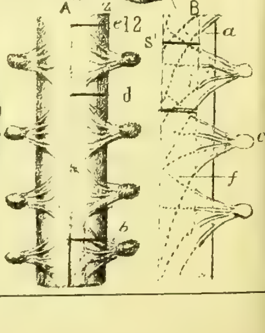

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Plate XV.—Nervous System.

Fig. 1. Vertical section of grey matter of cerebral convolutions, shewing six alternate light and dark layers. *a.* External light layer, with capillaries entering from the meninges, containing nuclei imbedded in molecular matter ; *b.* form of cells in deeper layers ; *c.* tubular white matter. 250 diam.

Fig. 2. Vertical section of external grey matter in leaflet of cerebellum. *a.* Molecular layer, with large cells sending off branched processes ; *b.* granular layer ; *c.* tubular white matter. 250 diam.

Fig. 3. General appearance and attitude of pigeon after removal of cerebral lobes. (*Dalton.*)

Fig. 4. General appearance and attitude of pigeon after removal of cerebellum. (*Dalton.*)

Fig. 5. Skull of Burke, a notorious murderer, executed in Edinburgh in 1828, with the supposed organ of destructiveness small.

Fig. 6. Skull of Pepy, a noted pirate and murderer of the West Indian seas, with the smallest organ of destructiveness known. His skull was sent to the Edinburgh Anatomical Museum by Captain Graham, R.N., brother of the late Professor of Botany, who captured him.

Fig. 7. Skull of Haggart, a noted thief in Edinburgh, who was hung for murdering his gaoler, with acquisitiveness and destructiveness small.

Fig. 8. General type of Saxon skull.

Fig. 9. Skull with great prominence of occipital bone.

Fig. 10. Section of and internal view of the same, shewing thickening of bone and deep groove, in which was lodged the enlarged *torcular Herophili.*

Fig. 11. Transverse section through middle of human *medulla oblongata.* *b*, *b.* Posterior pyramids, on each side of the posterior median fissure ; *b*, *c.* posterior column ; *d.* posterior part of antero-lateral column ; *e.* expanded extremity of posterior horn ; f, d^1, d^1. fibres forming the decussation ; f^1. anterior horn ; *t.* central grey substance behind the canal ; *z.* anterior median fissure. 5 diam. (*Lockhart Clarke.*)

Fig. 12. A. View of posterior surface of rabbit's spinal cord. *d*, *e.* Two sections dividing posterior columns. B. Diagrammatic view, shewing the manner in which nerve fibres of the spinal roots are distributed in the grey matter. *a.* Posterior white column ; *f.* grey matter ; *c.* ganglion on posterior spinal root.

NERVOUS SYSTEM. Plate XVI.

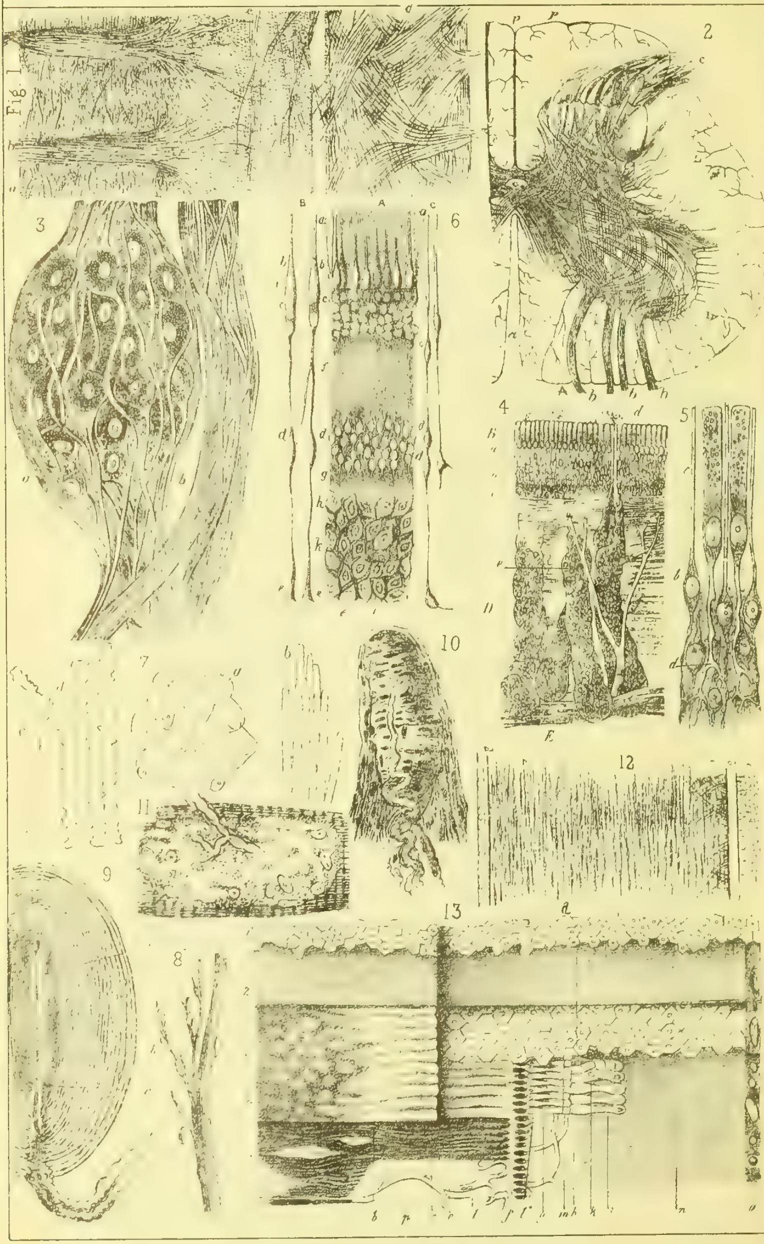


Plate XVI.—Nervous System.

Fig. 1. Longitudinal section through the lumbar enlargement of the spinal cord. *a.* Anterior column; *b.* anterior roots of nerves; *c.* mode of distribution: spreading out in all directions in grey matter, like a brush; *d.* decussation of fibres in posterior white column. (Reduced from figure of *Lockhart Clarke.*)

Fig. 2. Transverse section of spinal cord through the middle of the lumbar enlargement. A. Anterior column. P. Posterior column. L. Lateral column. *a.* Anterior median fissure; *p.* posterior median fissure; *b, b, b.* anterior roots of spinal nerves; *c.* posterior root; *f.* spinal canal. The ganglionic cells are not represented. (Reduced from figure of *Lockhart Clarke.*)

Fig. 3. Roots of a spinal nerve. *a.* Structure of ganglion on posterior, or sensory, root; *b.* anterior, or motor, root. (*Leydig.*)

Fig. 4. Vertical of the Schneiderian membrane of the olfactory region of a fox. B. Epithelium. *a.* Broad end of cells; *b.* nucleated deeper layer; *c.* deepest cell layer. D. Fibrous layer of Schneiderian membrane. *d.* Excretory duct from *e.* glands of Bowman; *f.* branches of olfactory nerve. E. Olfactory nerve. 108 diam. (*Ecker.*)

Fig. 5. Cylindrical epithelial cells from the olfactory region of a man. *a.* Epithelial nucleated cell; *b.* nerve cell, with straight process *c*; *d.* internal branching filaments of the epithelial cell. 350 diam. (*Ecker.*)

Fig. 6. Vertical section of a small part of the retina. A. Entire section of a small part of the retina. B. Two cones, represented separately in their connection with the fibres of Müller and other structures. C. Two rods, represented separately in their connection with the granules, fibres of Müller, and the nerve cells. 1. Columnar layer—*a.* in A and C, the rods, in B, the terminal part of the cone; *b.* cones: 2. Granular layer—*c.* outer layer of nuclei (striated corpuscles of *Henle*); *d.* inner layer of nuclei; *f.* inter-nuclear layer: 3. Nervous layer—*g.* fine molecular substance outside *h,* the nerve cells; *k.* nerve fibres; *l. membrana limitans;* *e.* inner ends of the fibres of Müller, resting on the limiting membrane. 350 diam. (*Kölliker.*)

Fig. 7. Structure of crystalline lens. *a.* External layer of nucleated cells; *b.* fibres of human lens; *c.* of ox; *d.* of cod. 250 diam. (*Todd and Bowman.*)

Fig. 8. Nerve from the finger, shewing Paccinian corpuscles, natural size.

Fig. 9. Paccinian body from mesentery of cat. *a.* Nerve tube, terminating in a fine filament, *c, c*; *b.* concentric series of layers of fibrous tissue. 250 diam. (*Ecker.*)

Fig. 10. Touch-body of Wagner, treated by acetic acid. 250 diam. (*Ecker.*)

Fig. 11. Muscular fasiculus, with nerve entering its substance, and supposed ganglionic nuclei. 300 diam. (*Kühne.*)

Fig. 12. Vertical section through the cornea. A. Anterior surface. *a.* Conjunctival epithelium; *b.* anterior elastic lamina; *c.* layers of cornea proper joined to anterior elastic lamina by crossed fibres; *d.* posterior elastic lamina; *e.* membrane of Descemet. 80 diam. (*Todd and Bowman.*)

Fig. 13. Soft *lamina spiralis* of the cochlea. 1. View from above of the *membrana tectoria* of Corti. 2. *Ligamentum membrana tectoriæ,* immediately below this. 3. *Habenula sulcata.* 4. Internal rods of Corti. 5. Auditory nerve. *a, a.* Ligament of the cochlea; *b. habenula sulcata; c.* its toothed free margin; *d.* parenchymatous cells between the *ligamentum membrana tectoriæ* and the *membrana basilaris, m; e.* internal flat rods or staves of Corti; *f.* oval grooves, through which pass fine nerves, l^{*1}; *g.* middle rods of Corti; *h.* external square-shaped extremity of the middle rods, *g; i.* outer rods of Corti; *k.* terminal ganglion cells of Corti; *l.* bundles of cochlear nerves; l^1. minute nerves coming through the grooves, *f; m.* position of *membrana basilaris ; n. zona pectinata,* terminating externally in the *ligamemtum membrana basilaris.* (Reduced from figure of *Ecker.*

REPRODUCTION. Plate XVII

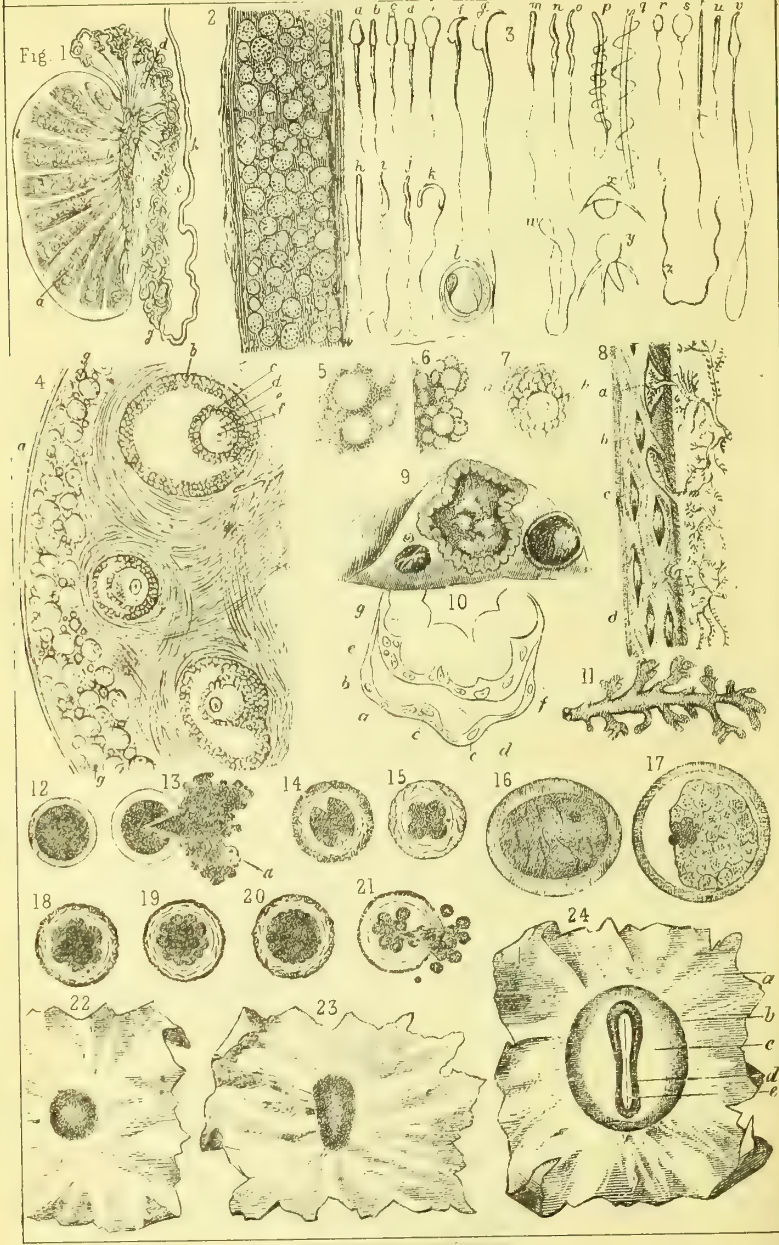


Plate XVII.—Reproduction.

Fig. 1. Section of a testicle. *a.* Convoluted *tubuli seminiferi; b, s. vasa recta; c, f. rete testis,* in the *corpus Highmorianum; d. globus major; e.* body of the epididymis ; *g. globus minor; h. vas deferens; i i. tunica albuginea.*

Fig. 2. View of a portion of one of the *tubuli seminiferi*, shewing molecular matter, and cells of various sizes in which the spermatzoids are developed. (250 *diam.*)

Fig. 3. Spermatzoids of various animals. *a.* Spermatzoids of man, viewed on the surface ; *b.* the same viewed edgeways ; *c.* the same with granule at summit of head ; *d.* the same edgeways ; *e.* dog ; *f.* mouse ; *g.* rat ; *h.* frog ; *i.* snake ; *k.* lizard ; *l.* spermatozoid coiled up in cell ; *m.* wild duck ; *n.* shrike ; *o.* finch ; *p.* Bombinator igneus ; *q.* a magnified view of a portion of the same ; *r. perch; s.* loach ; *t.* shark ; *u.* lamprey ; *v.* Helix (a snail) ; *w.* planaria ; *x.* a crab ; *y.* Pagurus (hermit crab) ; *z.* earthworm.

Fig. 4. Section of a portion of an ovary. *a.* Fibrous coat ; *b.* a Graafian vesicle, shewing at c the *tunica granulosa; b. membrana granulosa; d. zona pellucida* and yolk ; *e.* germinal vesicle ; *f.* germinal spot ; *g.* Graafian vesicles forming. In the middle of the figure, a Graafian vesicle is seen in a more advanced stage of development, and at the bottom we have one still farther advanced. These lie in a fibrous stroma.

Figs. 5 and 6. Formation of ova by molecular aggregation.

Fig. 7. A primitive Graafian vesicle, *a,* containing an ovum *b.*

Fig. 8. Section of the mucous membrane of the uterus, shewing at *a, c,* and *d,* a fœtal tuft projecting into a uterine sinus : and at *b,* another sinus.

Fig. 9. Section of an ovary shewing in the centre a recent *corpus luteum*, on the right hand an older one, and on the left one still older, much reduced in size by contraction.

Fig. 10. The extremity of a placental villus. *a.* The external membrane of the villus,—the lining membrane of the vascular system of the mother ; *b.* the external cells of the villus,—cells of the central portion of the placental decidua ; *c, c.* germinal centres of the external cells ; *d.* the space between the maternal and fœtal portions of the villus ; *e.* the internal membrane of the villus,—the external membrane of the chorion ; *f.* the internal cells of the villus, the cells of the chorion ; *g.* the loop of umbilical vessels.

Fig. 11. A placental villus.

Fig. 12. An ovum from the bitch freed from the granular membrane, shewing the dark internal yolk, and clear external *zona pellucida.* (50 *diam.*)

Fig. 13. The same ovum lacerated with a needle. The yolk has flowed out, shewing the germinal vesicle, *a,* with its germinal spot. (50 *diam.*)

Fig. 14. The ovum has encountered spermatzoids, which are seen adherent to the *zona pellucida.* Fecundation has taken place ; the spermatzoid, which has penetrated the transparent zone, together with the germinal vesicle, has been dissolved in the yolk, which is divided into two masses. (50 *diam.*)

Fig. 15. The yolk divided into four masses. (50 *diam.*)

Figs. 18 and 19. The process of division in the yolk further illustrated. (50 *diam.*)

Fig. 20. The yolk now reduced by division to a large number of molecular cells. (50 *diam.*)

Fig. 21. The molecular cells rendered visible by laceration of the ovum. They contain a clear space in their centres. (50 *diam.*)

Fig. 17. An ovum further developed after it has been placed in water for a short time. In consequence of endosmose, the internal membrane is separated from the *zona pellucida,* and is seen to be formed by the cells which have coalesced. This is the germinal membrane with the germinal area composed of an extra layer of cells. (50 *diam.*)

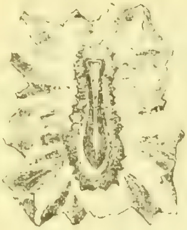
Fig. 16. An ovum much larger, taken from the uterus, moistened with water. The germinal membrane is somewhat separated from the *zona pellucida,* and thrown into folds. (10 *diam.*)

Fig. 22. Portion of the germinal membrane surrounding the germinal area, cut out from a further developed ovum. A clear space in the area called *area pellucida* is apparent. (10 *diam.*)

Fig. 23. A similar piece from a somewhat older ovum. The germinal area has become oval. (10 *diam.*)

Fig. 24. The germinal area is now greatly enlarged in the germinal membrane ; *a.* germinal membrane ; *b.* limit of vascular area ; *c. area pellucida; d. laminæ dorsales; e.* Primitive groove.

REPRODUCTION. Plate XVIII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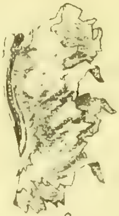
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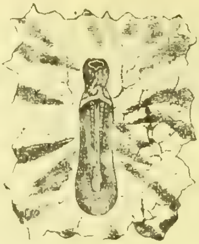
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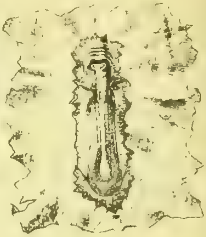
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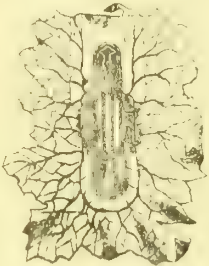
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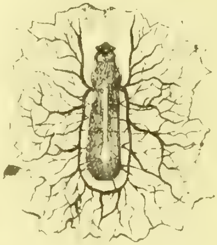
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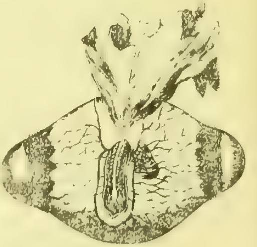
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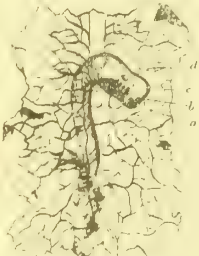

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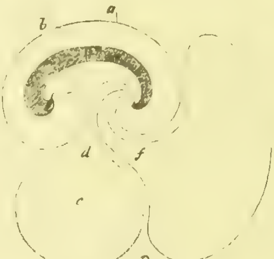

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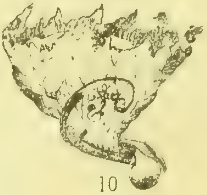
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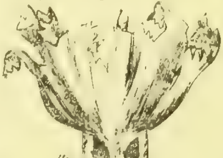

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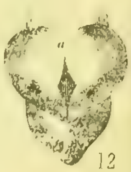

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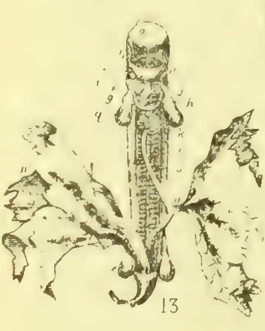
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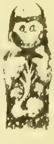

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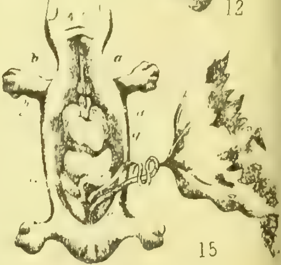

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Plate XVIII.—Reproduction.

Fig. 1. Portion of germinal membrane, with the embryo from an ovum twenty-four hours older than Fig. 24, Plate XVII. The primitive groove is not yet closed, but is much stronger, especially above. Here three swellings are observable, which are the three primitive brain-cells. At the inferior end, the groove is of a lancet shape (*sinus rhomboidalis*). In the centre of the groove is a thin streak, the commencement of the *chorda dorsalis*. Six square cells are formed on each side, the commencement of the vertebral column. The germinal membrane is now composed distinctly of two layers, the upper of which (*the serous* or *animal layer*) is cut close round the embryo, shewing more distinctly the lower (the *mucous* or *vegetative layer*). (10 *diam.*)

Fig. 2. The same embryo, seen sideways, whereby the elevation of the dorsal laminæ, and the groove between them, are better seen. The head is already distinctly elevated above the germinal membrane. (10 *diam.*)

Fig. 3. An embryo twelve hours older than the former one, turned round and examined on the under or abdominal surface. The head with the broadened-out first brain-cell is seen coming forward. Immediately below this an S-shaped tube is seen, which is the rudimentary heart. The lower end branches off on each side to join the vascular network, forming the *venæ omphalo-mesentericæ.* The visceral or abdominal cavity is seen open below, causing the embryo to resemble somewhat the appearance of a partly-decked boat. (10 *diam.*)

Fig. 4. The same embryo seen from above. The primitive groove is now for the most part closed over. The first brain-cell is widened out laterally, and bent forwards. The posterior ones are altered in shape from absorption of fluid. There are two vertebral cells. At both ends of the primitive groove folds of the serous layer are visible—the commencement of the amnios. The serous layer is cut close round the embryo ; and upon the mucous layer, fine lines, in the form of a network, are visible—the commencement of the *vascular layer.* (10 *diam.*)

Fig. 5. An embryo from an ovum supposed to be twenty-three or twenty-four days old, seen from above. The primitive groove is now completely closed, to form the medullary tube, and exhibits above the three primitive brain-cells. The first of these is seen to be so expanded laterally as to form at each side the embryo eyes. The embryo ears are also seen at each side opposite the third brain-cell. The upper and lower ends of the embryo are now inclosed in a backward fold of the serous layer, which, however, is still open in the centre. The blood vessels in the vascular layer are now fully formed. (10 *diam.*)

Fig. 6. The same embryo seen from below. The head is strongly bent forward, so that the first brain-cell and embryo eyes are best seen on this surface. Below these, two notched processes are seen, which are the first visceral arches. Below these again, the S-shaped heart—terminating, above in the aorta, below in the *venæ omphalo-mesentericæ.* The heart now pulsates, and a circulation is established over the vascular area. (10 *diam.*)

Fig. 7. An entire ovum, with the embryo somewhat older than the last. The villous chorion is raised off the entire centre of the egg, which is suspended by it at one point, where the folds of the serous layer have completely closed over the back to form the amnios. The embryo lies with its interior half in the plane of the vascular and mucous layers ; whilst the head and superior half is prominent, and inclosed by them. At the sides are seen both the *arteriæ* and *venæ omphalo-mesentericæ,* which communicate with the plexus of the vascular ayer, and terminate in circular rings, the *venæ terminales,* leaving the two poles of the ovum bare. (5 *diam.*)

Fig. 8. The same embryo, removed with its membranes, and viewed from the internal surace of the ovum, sideways. The head and upper portion is seen surrounded by the amnios. n the head is observable the brain, divided into anterior, neighbouring, and middle brain, *a, b, c ;* the third brain-cell, *d ;* eyes, *e ;* ears, *f ;* not yet connected with the third brain-cell. There are three visceral arches. The heart is further developed, prominent, and surrounded by the serous membrane. The lower portion of the embryo is covered with the vascular and mucous layers. (5 *diam.*)

Fig. 9. Diagram representing the mode of formation and position of the three embryonal sacs. *a*, Embryo—*b*, amnios—*c*, umbilical vesicle—*d*, the vitelline duct, or pedicle of the umbilical vesicle—*e*, allantois—*f*, the urachus or pedicle of the allantois, afterwards the urinary bladder.

Fig 11. The lower end of an embryo some hours older than that in Fig. 8. The mucous and vascular layers are drawn upwards, so that not only is the visceral cavity seen, but the lower portion of the intestinal canal, *a*. At the lower portion of the embryo are two small swellings, *b*, *b*, the commencement of the *allantois*. (10 *diam.*)

Fig. 12. The lower end of an embryo twelve hours older than the last. The allantois now forms a sac, the two halves of which, however, are not yet closed. (10 *diam.*)

Fig. 10. The embryo of an ovum twelve hours older than the last, suspended by the vascular and mucous layers. All the different parts formerly referred to may be seen further developed. The superior extremity is prominent. In the visceral cavity two long striated bodies are seen, the *Wolffian bodies* ; and the allantois is now so enlarged as to hang out of the visceral cavity, covered with a network of vessels in connection with the vascular layer. (5 *diam.*)

Fig. 14. The head of the same embryo. *a*, Anterior brain-cells—*b*, eyes—*c*, second brain-cell—*d*, first visceral arch—*e*, process thereof—*f*, three lower visceral arches—*g*, right, and *h*, left auricle—*i*, left, and *k*, right ventricle—*l*, aorta, with aortic branches to the visceral arches. (10 *diam.*)

Fig 13. An embryo older than that represented in Fig. 14, seen in front. *a*, Nasal apertures—*b*, eyes—*c*, first visceral arch, now the under jaw—*d*, second visceral arch—*e*, right, and *f*, left auricle—*g*, right, and *h*, left ventricle—*i*, aorta—*k*, liver ; between its two lobes is seen the cut *vena omphalo-mesenterica*—*l*, stomach—*m*, intestinal canal, terminating in the umbilical vesicle—*n*, *o*, Wolffian bodies—*p*, allantois—*q*, upper, and *r*, under extremity. (5 *diam.*)

Fig. 15. Embryo of an egg about four weeks old. *a*, Trachea and œsophagus—*b*, thymus gland—*c*, right, and *d*, left auricle—*e*, right, and *f*, left ventricle—*g*, left, and *h*, right aorta—*i*, *i*, *i*, three lobes of the liver—*k*, stomach—*l*, intestinal coils, which by a band, *m* (the former *ductus omphalo-mesentericus*), are in connection with the umbilical vesicle *n*—*o*, Wolffian bodies. (5 *diam.*)

PRACTICAL PHYSIOLOGY. **Plate XIX**

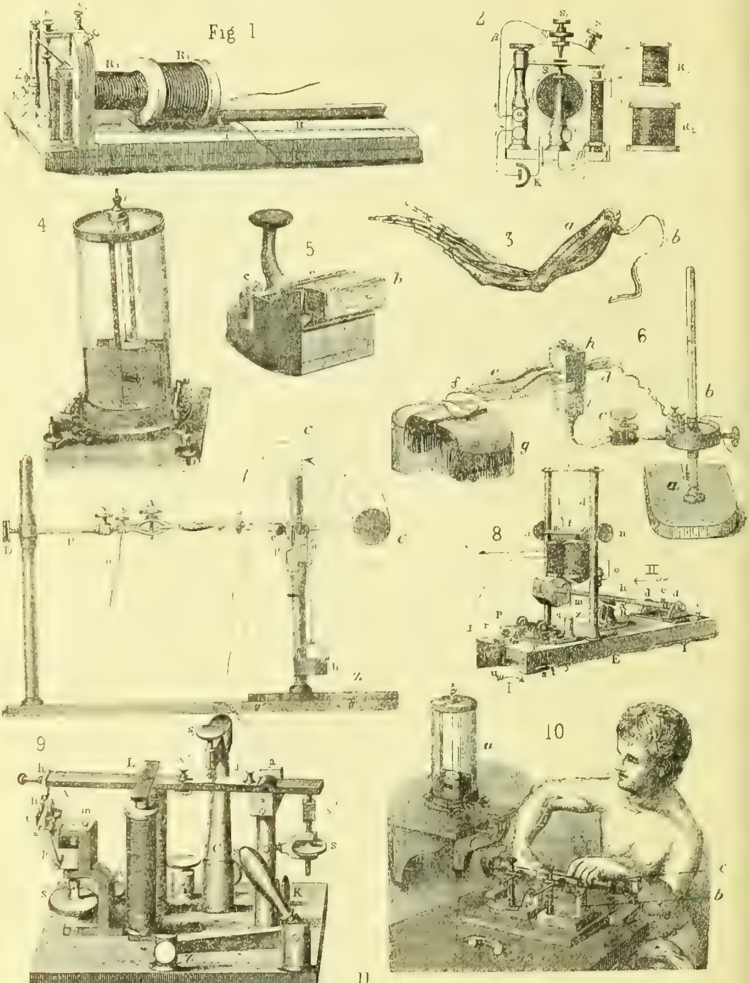

Plate XIX.—Practical Physiology.

Fig. 1. Du Bois-Reymond's induction-apparatus. R 1. Primary coil; R 2. secondary coil; the upper B is the groove in which the secondary coil slides. B B. Wooden stand. 1. Scale graduated into millimetres. *b.* Electro-magnetic apparatus for attracting Neef's hammer. *k.* Screw for attaching wire from positive pole. Z. Screw for wire in connection with negative pole. k' $S_{\prime\prime\prime}$. Attachments for a wire when Helmholtz's modification is employed (see Fig. 2 β). S′. Screw, the point of which establishes a connection with the back of the spring.

Fig. 2. The end of Du Bois-Reymond's apparatus, shewing on the right hand a diagrammatic view of the primary and secondary coils. *a.* Screw for attaching the wire β passing to $S_{\prime\prime\prime\prime}$, as used in Helmholtz's modification. *b.* End of the primary coil. S. Screw point which touches the under surface of the spring, and is placed on the top of the middle pillar, in the base of which there is an attaching screw, *x.* $S_{\prime}$. Screw, the point of which touches the back of the spring when the apparatus is used in the ordinary way. $S_{\prime\prime}$. Attachment screw for the wire passing in the direction of the arrow to R_1, the primary coil. The lower arrow indicates the wire passing to the magneto-electric apparatus R_2, secondary coil. *k.* The battery.

Fig. 3. The limb of a frog skinned. *a.* The muscles of the leg; *b.* the sciatic nerve.

Fig 4. Multiplying galvanometer. *a.* Base; *b.* brass box; C. boxwood frame carrying coils of wire; *f f.* wires leading to galvanometer; *g.* screw for rotating *b.* *h, h.* Vertical brass bars supporting a horizontal bar, from the centre of which the astatic needle is suspended by a single silk fibre. *i′.* Screw for raising or lowering the needle.

Fig. 5. Non-polarizable electrode of Du Bois-Reymond. *a* S. Amalgamated zinc trough; *c.* attachment screws for wires. *e.* A rectangular piece of vulcanite for maintaining the cushion of blotting paper in position; *g.* film of moist clay laid on the cushion so as to protect the muscle from the irritant action of the solution of sulphate of zinc.

Fig. 6. Polarizable electrodes of Du Bois-Reymond. *a.* Wooden stand; *b.* round piece of vulcanite with screws; *c.* universal joint; *d.* binding screws; *h.* square block of ivory with wires, *e*, passing through it; *f.* the nerve lying on the triangular platinum electrodes; *g.* troughs containing cushions of blotting paper immersed in solution of sulphate of zinc.

Fig. 7. Muscle telegraph. A. Forceps holding the femur; B. handle of forceps, bearing at its end the screw S. The forceps may be elongated or shortened by drawing them out of the socket, secured by **S.** S. Screw for attaching wire *a* from positive pole of the battery; *h.* hook fixed to *tendo Achillis*, and having a wire, *x*, in connection with negative pole attached to it. *a a′* thread passing from *h* over the pulley *p′ p* and supporting the bucket *b*; *c.* a round counterpoise-weight attached to the end of the long arm above *p′*, bearing the disc C, which moves in the direction of the arrow. Z. Screw for fixing in the socket the upright pillar of brass bearing the telegraph. *g′ g′.* The stand of the whole instrument.

Fig. 8. Pflüger's falling apparatus or trip hammer. E I. Wooden stand; *d d.* uprights bearing the axle *e*, on which the handle *h* of the hammer *i h* moves. *i.* Head of the hammer; *m.* steel point attached to side of the hammer-head, for dipping when the hammer falls, into the trough X. *a′ b′* Z. Steel catch for holding securely the handle of the hammer when the head falls. *y.* Screw for attachment of wire in connection with negative pole on the same piece of brass as supports the trough *x.* *c.* Screw for wire from positive pole of battery. P. Lever working between two uprights, P, one end of the lever being seen at S (following the dotted line), and the other at *q.* *r.* Screw point which, when hammer head is elevated, is touched by the end of the lever, but is separated from it when the head falls. *t.* Screw for attachment of wire from positive pole; *u.* screw for the wire in connection with negative pole. The *closing* shock is given by the current passing in the direction *c, d, e, h, m, x, y;* while that of the *opening* shock passes thus: *t, p r, u.* Above the hammer head s the magneto-electric apparatus A for supporting it. *d d.* Two brass upright

pillars; c. transverse bar connecting *d d* at the top. *j.* Bar bearing underneath the two electro-magnets *f.* These may be elevated or depressed on *d d* by the screws *n n.* *O.* Wires connecting two Smee's elements with electro-magnet.

Fig. 9. Heidenhain's tetanometer. K. Upright brass pillar, having an attachment screw, and bearing the lever *h*, L, S″ *j*, *a*. *a*. Fulcrum of the lever; S″ *j*. two screws by means of which lever may be lengthened or shortened. L. Armature for the electro-magnet seen underneath, S′ V. C. Upright brass pillar bearing at top a horizontal arm, at end of which there is a screw S′, the point of which touches a bit of platinum on the upper surface of the lever. $S_{\prime\prime\prime}$. Attachment screw. $S_{\prime\prime}$. Attachment screw. $S_{\prime\prime}$, and $S_{\prime\prime\prime}$ are connected by a wire in the vulcanite stand not shewn. Z. Short brass pillar having a binding screw. The current is broken by pushing back the handle seen on the right, and thus elevating the brass arm *k*. S. Spiral spring, worked by screw S underneath for restraining the action of the lever. A. On left end of the instrument is the apparatus for beating the nerve. *h*. Small ivory hammer, at end of lever; *h*′. ivory groove in which hammer head *h* beats. *t*. Groove passing transversely for nerve A. *m*. Small roller for attaching the end of the nerve. *p*, Steel spring for retaining roller *m* in position. $S_{\prime\prime\prime\prime}$. Screw by which the apparatus above may be elevated or depressed.

Fig. 10. Arrangement of apparatus for demonstrating the presence of a current of electricity in the living body. The individual is grasping a wooden roller, having the index fingers immersed in the troughs. On his right hand the galvanometer is seen.

Fig. 11. The rheocord. S W. Platinum wire. S′ $W_{\prime}$. Another platinum wire. I *a*. Ivory bridge over which the wires pass at *σ σ*. Z. Piece of brass carrying two bottles filled with mercury A, capable of sliding along the platinum wires S W, and S′ $W_{\prime}$. O. 1000, Scale graduated into millimetres. P S. 1, 2, 3, 4, 5, and 6. Rectangular pieces of brass, which may be connected by brass stoppers, or pegs. P and Q. Short brass pillars, each bearing two attachment screws for wires *a a*. The dotted lines, marked on the right hand thus: $\left.\right\}$X, $\left.\right\}$V, II, I *c*, and I *b*, and passing round small ivory pulleys, represent German silver wires, connecting the pieces of brass, 1, 2, 3, 4, 5, and 6, when the stoppers are removed.

PRACTICAL PHYSIOLOGY. Plate XX

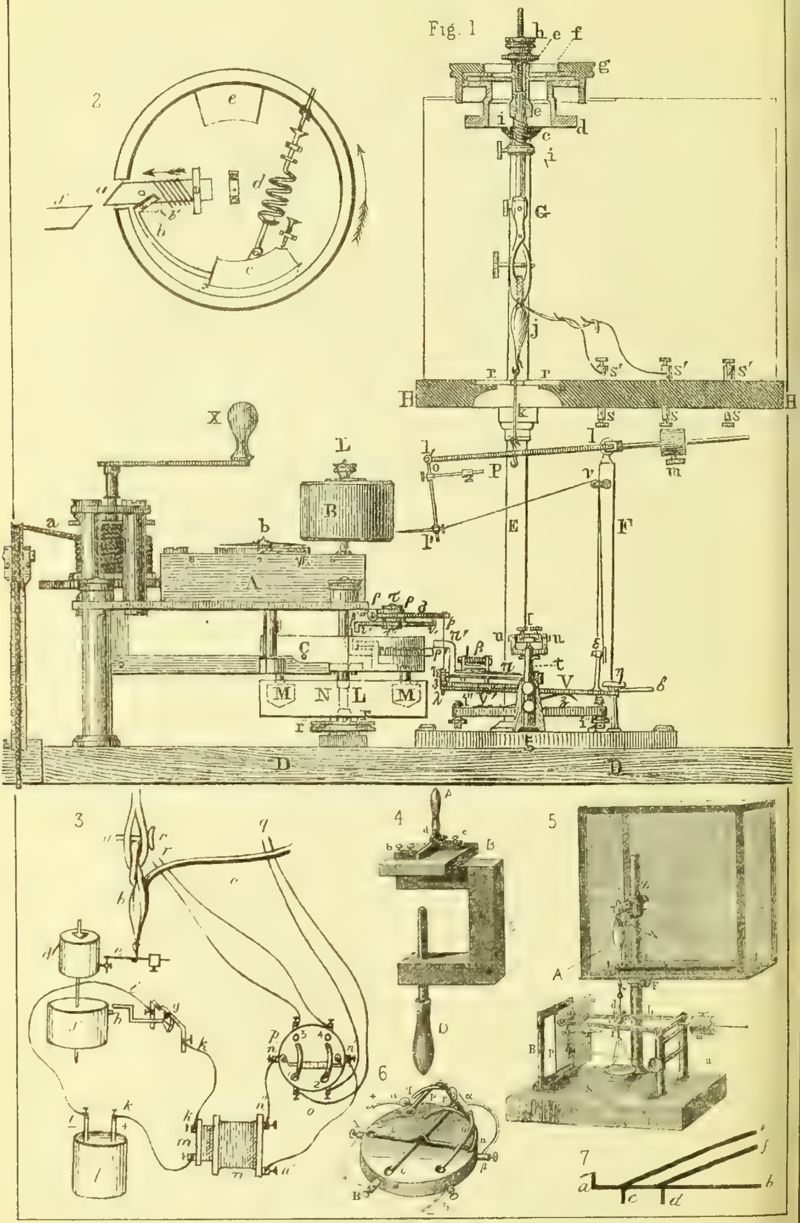

Plate XX.—Practical Physiology.

Fig. 1. Sectional view of the Myographion. A. Clock-work. B. Revolving cylinder. C. Box containing centrifugal apparatus. D. Wooden stand or base supporting the whole apparatus. E. Strong brass pillar supporting a square glass chamber, in which the nerve preparation is stimulated. F. Brass pillar supporting the lever apparatus *l l*. G. Brass forceps for holding the femur, provided with a binding screw at G. H H. Strong vulcanite floor of the moist chamber, having a round hole between *r* and *r*. L L. Vertical axis on which the cylinder B, and the centrifugal box C, revolve. M N L M is an open box placed beneath the centrifugal box C, but attached to the same axis, L L. In this open box there are two vertical plates, M M, which, by friction with the air, give steadiness to the movement of the machinery. Underneath M N L M, is a screw r'' *r*, for elevating or depressing it. P, on a line with O, a small brass rod, having a movable weight near P, for accurately balancing and adjusting the stylette P, which is observed in contact with the cylinder B. S S S. Three of the four attachment screws for wires coming from Pohl's Commutator. S′ S′ S′. Attachment screws in the interior of the moist chamber, connected through the vulcanite plate H H, with S S S. V′ V. Lever apparatus supporting the mechanism by means of which the primary current is broken in the centre of the bridge.

a. Cord passing from a drum, and having a heavy weight attached to the other end ; this is the motive power of the clock-work. The cord may be wound up by the handle X. *b*. Dial for indicating the rapidity of the clock-work. *c*. (Near the top of the figure) a spiral, by means of which the forceps G may be elevated or depressed, and secured by a screw seen opposite. *i*, *d*, *i*, *g*. An apparatus consisting of a circular box in the roof of the moist chamber, in which, by means of an eccentric movement of the plate *f*, and of a vertical movement of the screws *h e*, the forceps G may be brought over exactly the centre of the hole in the vulcanite floor, H H, marked *r k r*. *j*. *Gastrocnemius* muscle, having a hook in the *tendo Achillis*. *k*. Wire passing from the hook just mentioned, to another hook in the lever *l′ l*. *m*. A movable weight on the free end of the lever *l′ l* for balancing the latter. *r r*. Two circular glass plates for almost closing the hole in the vulcanite floor, a small perforation being left for the wire *k*. The more complicated parts of the machinery are marked by Greek letters, and can only be understood by comparing Fig. 1 with Figs. 2 and 3, or by examining the instrument.

Immediately under the point of the stylette P, there may be seen the apparatus for bringing it in contact with the point of the cylinder at the proper moment. $\rho\ \rho\ \partial$ Lever. $\tau\ \tau''$. Axis round which the piece of brass $v'\ v'$ moves when the end next the axis, L L, is knocked against by a small projection seen close to the axis, and marked β. At *p*, to the right of ε is the thread passing downwards to $\vartheta\ \lambda$, the end of the lever V′ V. This lever, V′ V moves on an axis in the pillar seen resting on a spring ξ. The spring is attached to a brass bar $i''\ i''$, which moves on an axis between two brass pillars, one of which is seen above ξ. On the right of V, there is a delicate pillar of brass, from the top of which, at ε, a thread passes upwards to the pulley *v*, and from thence downwards to the left to the end of the stylette P. Near the bottom of the pillar F, there is a small arm marked $\eta\ \delta$, by which the lever V′ V may be held down, and the stylette thus withdrawn from the cylinder. Now direct attention to the apparatus for breaking the primary current at a proper moment. In the interior of the centrifugal apparatus C, the dotted outline represents the out-springer, the end of which is seen at $\rho\ \rho$. $\pi'\ \pi$ is the rectangular arm, which, when pushed over to the left by ϱ, the out-springer, breaks the primary current in the centre of the bridge *t*. β. The spring for retaining the arm. Near the base of the pillar E, there is a screw, *u u*, for regulating the action of the lever apparatus V^1 V.

Fig. 2. View of the centrifugal apparatus marked C in Fig. 1. *a*. Point of the out-springer, which moves in the direction of the arrow, propelled by a spiral wound round it. *b*. Steel arm for retaining *a* ; attached to a movable weight *c*. The movement of the latter is controlled by a spring, *d*, which may be tightened or relaxed. *e.* Fixed weight acting as a counter-poise to *c.* *f.* End of the rectangular arm seen at *n′*, Fig. 1, and *h*, Fig. 3. The arrow to the right shews the direction in which the box revolves.

Fig. 3. Diagram shewing the arrangement of apparatus for determining the rapidity of the nerve-current. *a.* Forceps holding *femur; b. gastrocnemius* muscle; *c. sciatic* nerve; *d.* revolving cylinder; *e.* lever carrying the stylette; *f.* centrifugal apparatus; *g.* steel spring forming the bridge between the two pillars *k i; h.* end of out-springer, and above it the end of the rectangular arm; *k.* wire passing from primary coil *m* to one side or pier of the bridge in the myographion; *i.* wire from the other pier back to the battery *l*; *l.* the battery; *m.* primary coil of induction machine; *n.* secondary coil; *n″ n″.* Pohl's Commutator, having at p3, 4 wires going to stimulate a portion of the nerve *c*, close to the muscle at *r*, and at *o* 1, 2, wires passing to *q*, so as to stimulate at a distance from the muscle. The primary circuit is in the direction *l, m, k, g, i*, back to *l.* When this is broken at *g*, an induced current is sent from *n* either to *r* or *q*, on the nerve *c*, according as we place the Commutator.

Fig. 4. Du Bois-Reymond's key. B. Vulcanite plate. *b, c.* Rectangular pieces of brass, each bearing two screws. These may be connected by means of the handle *d.*

Fig. 5. Pflüger's Myographion. S. Wooden stand. B. Frame having a groove in which the glass plate P moves. F. Brass pillar bearing a square glass chamber for the muscle. L. Forceps for the *femur*, to which is attached the *gastrocnemius* muscle A with the *sciatic* nerve N. *a.* Brass pillars bearing at the top the double lever *b*; *c.* swivel apparatus for connecting the lever *b* with *d*, a long hook attached above to the *tendo Achillis*; *g.* a scale for a weight sufficient to draw down the lever after it has been elevated by the contraction of the muscle; *m.* movable weight for carefully balancing the lever.

Fig. 6. Pohl's Commutator. *a.* A round wooden disc, having six small holes filled with mercury, each having a screw for the attachment of a wire; + *a.* wire coming from positive pole of battery; −*b.* wire going to negative pole; P O. two pieces of wire permanently fixed at one end into + *a*, and − *b*, and the other ends held in close proximity by a glass tube S; *q, r*, and *m, n.* transverse arcs of wires, having their ends free, so that by moving the bridge P S O, the ends of the arcs may dip into either the holes α β, as seen in the figure, or into A B; α β. attachments for wires going to a nerve or muscle; A B. another pair of the same; *h* and *i*, transverse wires, *h* being bent in the middle so as not to touch *i.* The directions of the current may be as follow: (1.) *Without the transverse wires, h i.* In this case, the current will pass along a circuit, α β, when the ends of the arcs dip into the holes *r n*; but if the bridge be reversed, so that the ends *q, r* of the arcs dip into A B, the current will pass along a circuit from A to B. (2.) *With the transverse wires h i.* We can now send a current from α to β, or from β to α, that is, either up or down a nerve. As the bridge is placed in the figure, the direction will be + *a*, P, *r*, α, β, *n*, O,—*b*, and from thence to the battery. But if we now reverse the bridge, so that *q m* dip into the holes A B, the current will travel along the cross wires thus, ——— + α, P, *q*, A, cross wire *h, n*, β, α, *r*, cross bar *i, m*, O,—*b*, and from thence back to the battery.

Fig. 7. Form of tracings to be obtained on the cylinder of the Myographion. The horizontal line *a b* is the mark made by the stylette during the revolution immediately before the primary current is broken. The two oblique curved lines *c e, d f* are produced by the stylette being drawn upwards by the contraction of the muscle when the nerve is stimulated. Of these two, the line *c e* is that produced when the stimulus is applied close to the muscle; while *d f* is caused by the contraction when it is applied at a distance from the muscle. The short distance between the points where these curves leave the horizontal line *c d* indicates the length of time the nerve current occupied in passing from the distant to the near point of stimulation.

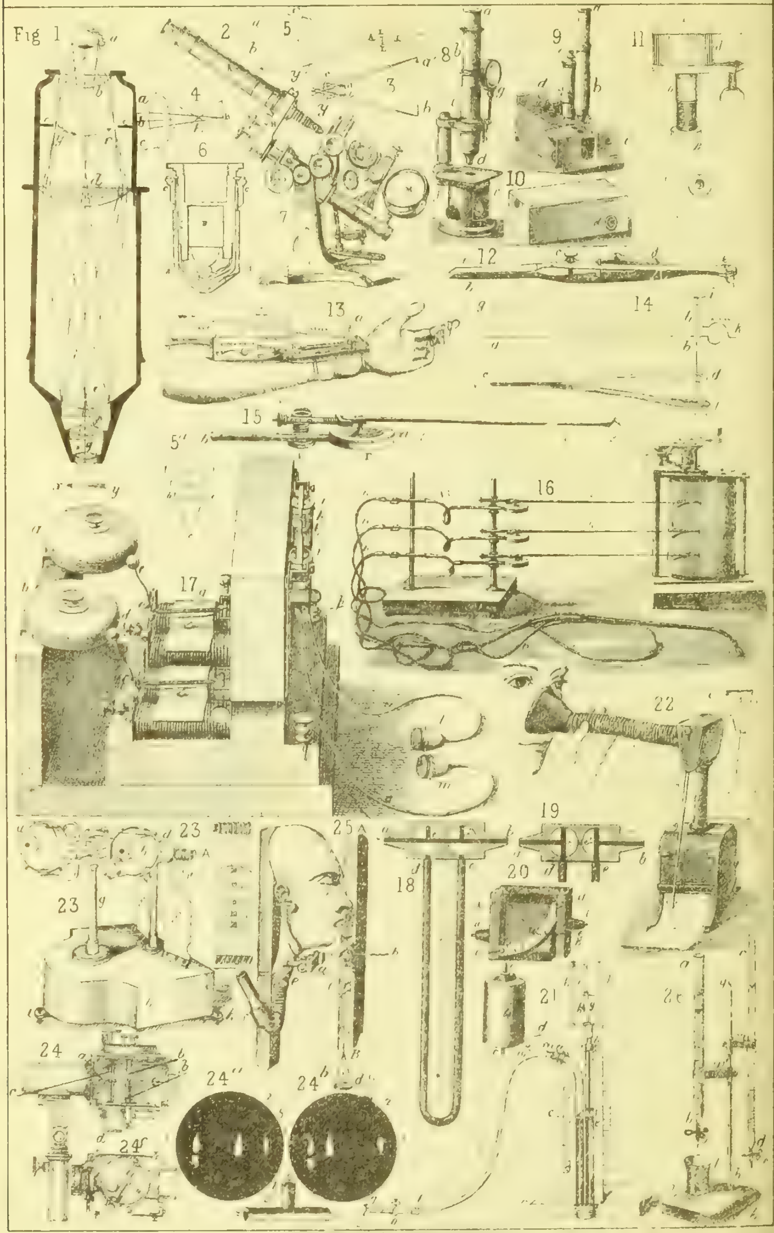
Fig 1
5″
24″
25 A
B

Plate XXI.—Practical Physiology.

Fig. 1. Section of a compound achromatic microscope. *a.* Eye of observer ; *b.* eye-glass ; *c c.* stop in the eye-piece ; *d.* field glass. The letters, *b*, *c c*, and *d*, represent the eye-piece, *e*, *f*, and *g*, the objective, consisting of three achromatic lenses. The arrow, *x y*, beneath the objective is seen magnified and inverted and curved at *y x*.

Fig. 5. Diagram to illustrate chromatic aberration. *x y.* A bi-convex lens ; *b.* a ray of light passing directly through *x y* ; *a b.* two rays of light dispersed by *x y*, so that the violet rays come to a focus at A, and the red at T. L L. a screen placed mid-way between A and T.

Fig. 5^a. View of three achromatic lenses ; *a b c* is the angle of aperture of the lenses.

Fig. 3. Diagram to illustrate the theory of enlargement. *x y.* A bi-convex lens through which rays of light pass to the eye from the small object *a b*, and which so refracts these that they enter the eye at such an angle as if they came from a large object *a' b'*. *a b* consequently appears magnified to the size *a' b'*.

Fig. 4. Diagram to illustrate spherical aberration, shewing the rays *a c* impinging on the surface of the lens near the margin brought to a focus at A, while those passing through the centre *b*, not being so much refracted, meet farther off, at B.

Fig. 2. Ross' compound achromatic microscope with movable stage and Gillett's condenser. A. Body of microscope. B. Rectangular arm supporting it. D. Coarse adjustment. F. Fine adjustment. M. Mirror, concave on one side, plane on the other. G. Gillett's condenser fitted beneath the stage. K S. Bull's-eye condensers for reflecting light on opaque objects. 7 is opposite the strong brass pillars supporting the microscope.

Fig. 6. Section of a compound objective of Ross, shewing three achromatic lenses and the arrangement for correcting the lenses for use with covered and uncovered objects. B. Tube carrying the two upper lenses ; A A. a cylinder carrying the lower lens ; C C. screwed ring for approximating A A to B.

Fig. 8. Oberhauser's microscope. *a.* Eye-piece ; *b.* body ; *c.* split tube ; *d.* objective ; *e.* mirror ; *f.* fine adjustment ; *g.* condenser.

Fig. 9. Nachet's pocket microscope. *a.* Eye-piece ; *b.* body ; *c.* fine adjustment ; *d.* box for containing the microscope and lenses, &c., and on the under surface of the inverted lid the microscope is fixed, as shewn in the figure ; *e.* mirror.

Fig. 10. The same instrument seen closed. *d.* A small button for moving the mirror.

Fig. 11. Stirling's section cutting apparatus. A. View from the side. B. View of the top. *a.* Screw for fixing apparatus to a table ; *b.* socket in which the fine threaded screw *c* works, pushing up the bottom of the circular box *d.*

Fig. 12. Valentine's knife. a, *b.* Blades ; *c.* screw for fixing the distance between the blades ; *d.* steel catch for holding blades together at the joint *e.*

Fig. 13. Sphygmograph of Marey affixed to the left wrist. The names describe the parts of the apparatus. The arrows shew the direction in which the card moves by clock-work. *a.* The upright rod in connection with the spring resting on the artery.

Fig. 14. Diagram of the essential parts of the sphygmograph. *a*, *b.* Lever ; *c*, *d.* fixed bar for attachment of spring *e f* ; *f.* button for resting on the pulse ; *g h.* dotted lines indicating the position of lever *a b* when elevated ; *k.* spring for regulating movements of lever ; *i.* head of upright rod, resting below on *f*, and which, by a little metal shoulder, elevates the lever *a b.*

Fig. 15. Marey's drum or tambour for obtaining delicate tracings of pulsations. T. The drum. *a.* Aluminium plate resting on the drum ; *b.* tube communicating with the drum. E. Ring by which the apparatus is fixed on an upright brass rod. *l l.* A long light wooden lever. P. A pen point at the end of the lever for making tracings.

Fig. 16. Marey's cardiograph for obtaining simultaneous tracings from different parts of the apparatus. On the right is seen a revolving cylinder for obtaining tracings. *le, lv, lc.* Levers moved by drums, which are seen under A3 connected with india-rubber tubes ; *te*, *tv*, *tc*, lying in front of the instrument, are india-rubber tubes filled with air, and having at V and *c*, small conical bags, for insertion into the blood vessels or into one of the cavities of the heart.

Fig. 17. Sphygmosphone of Upham, for discriminating between the times of alternate pulsations by sound. *a b.* Bells ; *c d.* hammers worked by the two electro-magnets *g* ; *e*, *f.* keepers of the electro magnets *g*, having *c d* attached ; *i i'.* bell-shaped glasses, the mouths being covered with india rubber, and having round metallic plates resting on them supporting the levers *k k'* ; *l m.* two similar bell-shaped glasses for receiving the impulse from the heart and wrist. The glasses *i i'* and *l m*, and the india rubber-tubing connecting them are filled with water. *p*, *q.* Connectors for wires leading from a battery and conveying electricity to work the electro-magnets.

Figs. 18 and 19. Volkmann's hæmadromometer for measuring the rapidity of the circulation of the blood. *a b*. Nozzles for insertion into the artery ; *c c*. tubes connected with a stop cock, so that the current may be caused to flow from *a* to *b*, as seen in Fig. 18 or along the U-tube *d e*, as seen in Fig. 19. In Fig. 18 the limb *e* of the U-tube is provided with a scale, but in most instruments the scale passes along the whole length of the U-tube.

Fig. 20. The essential part of Vierordt's hæmatachometer, for measuring the rapidity of the circulation. A B. Square metallic box, two sides being made of glass ; *a b*. nozzles for insertion into the artery ; *c*. a pendulum hanging in the box, near the point of entrance of the blood at *a* ; *d*. a graduated arc for measuring the deviations from the perpendicular of the pendulum ; *e*. the pendulum as moved by a stream of blood through the box.

Fig. 21. The kymographion of Ludwig, for measuring blood pressure, and also for measuring the time occupied by pulsations. *a*, *d*, *e*. A U-tube containing mercury, the level of which, in the two limbs, is seen at *d* and *e*. *l*, *n*, *m*, *a*. A tube filled with a solution of carbonate of soda, the part *l*, *n*, *m*, *a*, being made of lead, while *a d* is glass. At *m a* is an accurately fitting screw-collar for uniting the two tubes ; *n*. an air hole in the leaden pipe provided with a stopper ; *l*. a connecting screw-collar between the part of the apparatus *q l*, which is made of brass and the leaden pipe ; *o*. a stop cock ; *g*. a T-shaped nozzle for insertion into the artery. At *c* and *e* are graduated scales opposite each limb of the U-tube, for measuring blood pressure in inches of mercury. The apparatus as described to this point is the hæmadynamometer of Poisseuille. The apparatus for registering the oscillations of the mercury is now added. *f*. A glass float on the surface of the mercury bearing a thin vertical rod *g* ; *b*. a screw-collar ; *h h*. two uprights, having thin wires, on which the transverse bar bearing the stylette *i* moves freely up and down in the same vertical plane ; *k*. a weight which acts as a counterpoise to the float and stylette ; *r*. is the square wooden stand of the instrument. To the left of 21 is seen a revolving cylinder, *b*, moving on an axle, *a c*, and having a stylette, *d*, in contact with it.

Fig. 21^b. A T-shaped nozzle for insertion into an artery by the ends *a b*, the tube *c* connecting it with the end of the leaden pipe *l n m*, in Fig. 21.

Fig. 22. The anapnograph of Bergeon and Kastus, for measuring the amount of air in inspiration and expiration, and for obtaining a tracing of the movements of respiration. O. India rubber nozzle ; T. india rubber tube ; V. aluminium valve ; H. wooden lever ; P. pen. *c*. Tracing obtained on the paper. N M. Box containing clock-work ; B. button for tightening or relaxing the lever H ; C. diagramatic view of interior of box, shewing 3, 2, the aluminium plate and lever. The dotted line, 4, shews movement of the lever in inspiration.

Fig. 23. The ophthalmotrope of Reute. *a*, *b*. Models of eye-balls ; *c*, *d*. brass plates through which cords pass representing the muscles of the eyes ; *e*. cords passing downwards over the brass plates *f*, *f*. The back of one of these plates *f*, *f*, graduated, is seen at A. *g*. Brass pillar supporting the apparatus ; *h*. wooden box, having in its interior a transverse roller to which the cords *e*, are attached ; *i*, *k*. levelling screws.

Fig. 24. The ophthalmometer of Helmholtz. *a*, *d*, *b*, *b*. brass box containing two plates of glass, *b*, *b*, which may be revolved by the pinion *a*, *c* ; *d*,. screw-head for moving the pinion. At *c*, is a portion of the telescope. The whole apparatus is mounted on a stand, having a universal joint. 24, *f*. A view from above of a circular brass plate (seen in Fig. 24, in the upper part of the box, in a line with *a*), toothed at the edge, for revolving the glass plates by means of pinions.

Fig. 24^a. Diagrammatic view of the reflections of a candle flame seen in the human eye, as adjusted for distant objects. 1. Cornea, erect ; 2. anterior surface of lens, erect ; 3. posterior surface of lens, inverted.

Fig 24^b. The same as adjusted for near objects. The anterior surface of the lens has become more convex, as 2 is seen nearer to 1 than in 24^a.

Fig. 25. Müller's apparatus for shewing the production of voice. *a*. Forceps for compressing the thyroid cartilage, so as to approximate the cords ; *b*. movable handle of the forceps ; *c*. cord passing from a hook attached to the upper margin of the thyroid cartilage, in the mesial line, over a small pulley ; *d*. scale or balance, at the end of *c*. By placing weights in *d*, the tension of the vocal cords may be increased at pleasure. A B. Wooden pillar supporting the forceps and pulley.

Fig. 26. A stand, *i k*, on which there is a pillar, *g h*, bearing two of Mohr's burettes, which may be elevated or depressed by the split tubes *m m* ; *a*, *b*, and *c*, *d*. glass burettes, graduated in millimetres ; *f*, *e*. Mohr's clips for compressing the short pieces of india-rubber tubing ; *l*. glass beaker placed under *a*, *b*.

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